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Academician, Russian Academy of Sciences
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Stratigraphy and Geological Correlation

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Stratigraphic Space or the World of Stratigraphy

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Abstract – Some key problems of stratigraphy are discussed, a number of stratigraphic subjects are suggested to be enlarged, and the stratosphere concept is considered. Special stratigraphic units introduced by the Russian Stratigraphic Code (litho-, bio-, climato-, magneto-, and seismostratigraphic) are classified as independent but complementary to its main units (local, regional, general). Since they complement each other, the consistency of two stratigraphic classifications, which were earlier termed as European and American, is shown. The applicability of four fundamental principles of stratigraphy to initially unlayered geologic bodies (intrusive, dike, and highly metamorphosed) is analyzed to conclude that they can not be considered as subjects of classic stratigraphy. In addition to the classic, the stratigraphy of special unit types, and geosphere stratigraphy are proposed to be distinguished. The subjects of the geosphere stratigraphy are deep planet shells including the upper mantle, and the Earth's crust, or major intervals of its section. The immense thickness of deep geospheres is considered as a quantitative and qualitative features of the geounits of higher rank. The geosphere sections are defined as geostratigraphic. They comprise the initially unlayered geologic bodies, which are in this context the subjects of geosphere stratigraphy rather than of its classic version. The stratisphere stretches down to the lower mantle.

General and theoretical problems of stratigraphy have often been discussed during the past years. Such discussions became especially active when two issues of the Russian Stratigraphic Code were under preparation. For some problems acceptable solutions were found and introduced into the codes as articles, whereas for other problems no consensus was attained, which was one of the reasons prompting this work. Below, I intend to clarify the relationship between basic divisions of stratigraphy and to draw attention to the concept of the stratisphere.

The problems are divided in several groups: (1) principal and special stratigraphic units; (2) relations between stratigraphic units and geologic bodies initially unlayered; (3) stratigraphy and deep geospheres; and (4) the stratigraphic space.

The definition of a science is based on (or is a function of) the definition of the subject to be studied. This can be stated in reverse order, since both are interrelated. The Russian Stratigraphic Code defines the subject of stratigraphy as follows: "a stratigraphic unit (straton) is a combination of rocks united in a certain manner and distinguished by features which allow us to determine the temporal and spatial relations, i.e., the succession in their formation and position in the stratigraphic section" (*Stratigraficheskii Kodeks* ..., 1992).

Let us remember four fundamental principles of stratigraphy introduced by S.V. Meien, D.L. Stepanov, and M.S. Mesezhnikov, and also some of my suggested additions (*Prakticheskaya* ..., 1984). We will need them when discussing the problems cited above.

Steno's principle: "... In a case of unbroken bedding, every underlying bed is older than the overlying" (the original statement of the author). Meien suggests a wider formulation: "Temporal (earlier/later) relationships between geologic bodies are controlled by their initial spatial relations and/or by genetic links" (Meien, 1989).

Huxley's principle (the principle of homotaxis): "If a direct observation is impossible, the stratigraphic correlation can be carried out by comparison of homotaxis (i.e., identical) factors successions, including environments and events of the past" (Meien, 1989; *Prakticheskaya* ..., 1984).

Meien's principle (the principle of chronological interchangeability of factors or events that those factors depict): "The different, partially overlapping spatial distribution and compatibility of stratigraphic factors provide their chronological interchangeability, which is a basis for intra- and interregional, up to planetary, correlation according to most conceivable factors" (Meien, 1989; *Prakticheskaya* ..., 1984).

The principle of unbiased reality and the unique character of stratigraphic units was suggested by Stepanov and Mesezhnikov: "Stratigraphic units (stratons), representing the result of geological events, reflect objectively the essence of those events and do not recur through time" (Stepanov and Messezhnikov, 1979).

The second and third principles do not correspond exactly to words in the book cited above, and are presented here in my formulation, which Meien did not object to (personal communication, July 3, 1982). In the same letter, he recognized the fundamental character of the fourth principle, which I supported (*Prakticheskaya* ..., 1984), and subsequently suggested that it be considered as a primary one.

1. PRINCIPAL AND SPECIAL STRATIGRAPHIC UNITS

Historically, different approaches to the structure of stratigraphy originated in Europe and America. Most of the European geologists (including the Russian) have recognized stratigraphy as a unitary science, whereas the American geologists, according to the Code of Stratigraphic Nomenclature (1961), distinguish several independent "stratigraphies" corresponding to different research methods.

Almost 20 years ago, V.V. Menner and I conditionally called these two tendencies the "European" and "American." Nevertheless, at the same time we concluded that, in spite of the proclaimed theoretical difference in opinions, all geologists of the Old and New World work together and understand each other quite well (Zhamoida and Menner, 1974). Later, we noticed that these theoretical differences in opinions appear to have vanished (Zhamoida and Moiseeva, 1980).

Together with the principal stratigraphic units (local, regional, and general) of combined validity reflecting their geographical distribution and different features characterizing them, the Stratigraphic Code of the USSR (1977) adopted units of local validity, as well as subsidiary units corresponding to the litho- and biostratigraphic units of the American codes (*Code of Stratigraphic* ..., 1961; *North American* ..., 1983). In this case, it would be more correct to consider the complex versus particular characteristics rather than substantiations.

The second edition of the Russian Stratigraphic Code (1992) represents the relationship between groups of units under discussion in a new manner. For the principal stratigraphic units, their geosystemic nature is only outlined. Once again, I would like to emphasize the usefulness of the views of Librovich's (*Stratigraficheskie* ..., 1954), Rotai (*Stratigraficheskaya* ..., 1960), Menner (1962), who indicated the causality of unit characteristics in both the general and local scales within the step-by-step evolution of the Earth's crust. Virtually, the combination of principal unit characteristics reflects historical steps of the entire outer geosphere (the Earth's crust), or a crust area as related to the evolution of bio-, hydro-, and atmosphere (Zhamoida, 1980; *Prakticheskaya* ..., 1984; *Stratigraficheskii* ..., 1992).

In the second edition of our Stratigraphic Code, the units similar to those in the American Code and defined with particular methods are called specific. There are five categories: litho-, bio-, climato-, magneto-, and seismostratigraphic[1]. These are classified as subsidiary and quite independent, but still supplementary to the principal stratigraphic units. Their number can be enlarged.

[1] The reasons for distinguishing just these categories are given in the Foreword and Introduction to the Stratigraphic Code (*Stratigraficheskii Kodeks*, 1992).

2. RELATIONSHIP BETWEEN STRATIGRAPHIC UNITS AND ORIGINALLY UNLAYERED GEOLOGIC BODIES

The numerous definitions for the subject of stratigraphy listed in the geological literature can be reduced to two: the first includes the factor of stratification (or layering) that is fixed just in the scientific name, the second does not consider this factor as principal and accepts any geological body (stratified and unstratified, layered and unlayered) as the subject of stratigraphy, if these bodies are, or can differ in their formation time. This problem was under consideration when the first draft of the Stratigraphic Code of the USSR was discussed at the plenary session of the Interdepartmental Stratigraphic Committee (ISC), where the votes were split.

The definition of a unit (straton), introduced in the Stratigraphic Code (1992), implies that principal features are those that determine the spatial-temporal relationship between the subjects of research. If this is the completed formulation, then the subjects would comprise all geologic bodies including intrusives, dikes, and highly metamorphosed massif (where the original layering is impossible to define). Yet further explanations limited the understanding of the subject of stratigraphy, as only a sheet-like body (usually layered) can occupy a certain position in the stratigraphic section.

Here I should explain what I consider as sections in geology. I distinguish them as geological and stratigraphic sections.

A geological section or profile cuts in a natural or artificial manner through geological units (series, bodies). The section can be oriented across or along the strike of sediments (even parallel to the bedding), and may include intrusives, dikes, and any unlayered bodies. It can be continuous or include different tectonic deformations (faults, unconformities, etc.). Such a section usually accompanies a geologic map of an area or a region. Using the geological section, a geohistoric column can be reconstructed to incorporate all geologic bodies with traces of all tectonic and other processes represented in the geochronological order of their formation, intrusion, and manifestation.

The stratigraphic section is a sequence of geological bodies with original bedding. The strata of this section can be inclined, vertical, overturned, folded, but almost always we can recognize the primary succession of their formation, and thus apply the so-called "law of superposition" at every interval of the section. A stratigraphic column can be compiled using this law. Often a geological section is at the same time a stratigraphic section.

During the discussion of the draft of the second edition of the Stratigraphic Code, the problem of stratigraphy subjects was again considered. In the North American Stratigraphic Code (1983), intrusives and highly metamorphosed rocks are included in stratigraphic study as an independent class of lithogenetic units, whereas in the second edition of the International

Manual on Stratigraphy these are considered as lithostratigraphic units of a "special kind" (*International Subcommission ...*, 1992).

Two thirds of the ISC members objected to the inclusion of intrusive and highly metamorphosed geological bodies into the stratigraphic study. But one third of the members believed that as much as the mentioned bodies are mostly inconsistent with the "law of superposition" but bear "geochronological information," they should be accepted as the subjects of stratigraphy. But what natural geologic body does not have "chronological information?"

In consequence, most of the participants of the ISC Plenary Session (November 22, 1990) were in favor of a more general definition of the stratigraphic subjects suggested by Meien, according to which stratigraphy "studies the spatial-temporal relations of rock complexes (geologic bodies) in the Earth's crust" (Meien, 1989).

I have always supported the first point of view on the subject of stratigraphy, though some statements of prominent stratigraphers advocating the second concept forced me to discuss this question here. I think it makes sense to consider how every concept agrees with the four fundamental principles of stratigraphy.

The original formulation of Steno's principle excludes the unlayered bodies from subjects of stratigraphy. Previously supporting a more general definition of this principle, suggested by Meien, I now doubt its unambiguity. Meien regarded (1989) Khalfin's request to account for the genesis of contacting geologic bodies (Khalfin, 1969) as too demanding. He, nevertheless, believed that only genetic considerations are this principle's basis, explaining that sedimentation is dependent on the Earth's gravitational field. We can accept the last statement, because the "law of superposition" is based on those regularities of sedimentary sequences that were formed under gravitation. However, the importance of the genetic factor in the stratigraphic unit definition ends right here. So, the evaluation of the relative age of originally layered bodies may be taken to be a primary factor. At the same time, the relative age determination of intrusives and dikes is secondary in significance, because it can be reliably estimated with the help of enclosing, originally layered formations.

It seems more valid to apply Steno's principle in the original formulation. Proposing a more general formulation of Steno's principle, Meien still operates within the stratigraphic units in the quoted books and later articles, which is to say, with geological bodies formed due to sedimentation, or, at least, with bodies of sheet-like form. In this case, excluding sills, the earlier/later relation will always be a function of the lower/upper relation if the bedding is unbroken.

I doubt that somebody will apply the Huxley's principle of homotaxis factors in order to correlate intrusive bodies, even if they were formed with repeated intrusions of magmatic mass. It seems that only exact age determinations (geochronometry) in the layered intrusive sequences could play a role of homotaxis factors here, but it is still unattainable; it seems almost impossible in the case of highly metamorphosed geological bodies, if the primary origin of the visible layering (stratification) is not proved reliably.

Meien's principle considering geological bodies as parts of a geosystem at first sight is in full accord with both the above conceptions, but emphasizes the necessity to choose those chronologically interchangeable factors of the homotaxis succession that can be conceivably accepted as a "correct" correlation. A direct link between this and preceding principles questions the possibility of its application to intrusive and highly metamorphosed bodies.

The fourth principle is quite appropriate for both conceptions.

Therefore, among the four fundamental principles of stratigraphy, the second and third are not applicable to intrusive (especially to dikes) and highly metamorphosed geological bodies, as well as the first principle, if we follow its original formulation.

We again should pay attention to significant peculiarities of such layered and unlayered (or stratified and unstratified) geological bodies as genetic, temporal, and spatial. We should disregard here the highly metamorphosed geological bodies because their genesis is ambiguous, and they can be both sedimentary in origin with lost bedding and initially magmatic (intrusive) units with acquired stratification, etc.

When comparing the sedimentary (including volcanosedimentary) layered units with intrusive, originally unlayered bodies, one notices different ways of their origin. Vectors of forces ensuring their formation are opposite in direction, i.e.: centripetal (relative to the Earth's center) during sedimentation and centrifugal for intrusions. In the first case, gravitation acts causing the initially layered bodies to form one above the other and "parallel" to the geoid surface; in the second case, deep processes result in the "initially radiated" intrusions of geological bodies (Zhamoida, 1980).

The lower and upper boundaries (stratigraphic) can be determined for strata; hence, a time span of their deposition can be defined and a stratotype can be selected. For the intrusives, only the upper boundary can be determined either conditionally, or with the help of enclosing layered units, i.e., we estimate only the time when the forming processes were completed. When discussing the draft of the second edition of the International Manual on Stratigraphy, I noted that it is impossible to choose stratotypes for intrusive geological bodies. As a way out, A. Salvador (*International Subcommission ...*, 1992) proposed to use intrusive type localities instead of stratotypes, but I can not agree with that.

In this connection, the principle of determination and preferable use of lower boundaries of unlayered units in their volume evaluation and correlation appears to be quite unapplicable. It is well known that this principle has become generally accepted, and from this

viewpoint the International Commission on Stratigraphy recommended to use the so-called "points of boundary global stratotype" (PBGS) for units of the general stratigraphic scale, which was taken into account in the second edition of the Stratigraphic Code of Russia (1992) as well.

The principle under discussion is also important in regard to regional and, to a certain extent, local units.

Finally, if intrusives can be regarded conditionally as peculiar local lithostratigraphic units and, occasionally, as regional units (in the case of a wide distribution) then I doubt that anybody can apply to them the terminology and nomenclature of common (international) units. That is why the instruction on geological survey on a scale of 1 : 50 000 (1986), recommends the use of legends for intrusive rocks based on geochronological data. It is not by chance that in the chapter devoted to the Precambrian (i.e., mostly to highly metamorphosed rocks) of the second edition of the International Manual on Stratigraphy (*International Subcommission* ..., 1992), Salvador regards the Archean and Proterozoic only in terms of geochronological units, "eons," but not in stratigraphic (chronostratigraphic) terminology.

From the mentioned Manual (see the chapter on lithostratigraphic units) it is evident that igneous and unlayered metamorphic rocks are "exotic" among the normal, layered (stratified) sedimentary rocks and volcanics. The text concerning those rocks contains many stipulations. However, among these stipulations there are some so principal that the mentioned rocks can not be regarded even as lithostratigraphic units of a "special kind." Let me note the three most essential: first, these units may be inconsistent with the hierarchy of chronostratigraphic units (and often they are) retaining only geochronological meaning; second, certain types of localities but not stratotypes characterize them; and third, it is suggested that in addition to geographic locality and rock type, the denomination of intrusive bodies should account for their forms (batholite, stock, dike, etc.), or include the term "intrusions."

The presented reasonings lead to the conclusion that any units corresponding to intrusive and highly metamorphosed geological bodies free of original layering can not be regarded as subjects of stratigraphy, though, like other natural bodies they bear the geochronological information. At lest they can not be considered as subjects of the traditional (classic) stratigraphy. The table presented illustrates this conclusion.

Classification, terminology, and nomenclature of intrusive, dike and highly metamorphosed geological bodies are presented in the Petrographic Code (*Petrograficheskii Kodeks*, 1992).

3. STRATIGRAPHY AND DEEP GEOSPHERES

Classic stratigraphy deals with layered structures of the Earth's crust. At the same time, continuous progress in direct and indirect studies on geology of deeper zones presented the problem of planetary stratification of the Earth's crust and subcrustal formations[2]. Can those investigations be incorporated into the sphere of stratigraphic studies? Such a question was raised by the well-known petrographer G.M. Gapeeva in 1971 when discussing the first draft of the Stratigraphic Code of the USSR.

The answer depends on the definition of a layer, or a layered structure. Yu.A. Kosygin assumes that such a structure "can be distinguished by different characteristics, i.e., may have a different nature... If one considers the layered structure in such a general sense that it should be inherent in the globe as a whole (spherical layered structure), in the Earth's crust, in its sedimentary cover, and in separate sequences of the cover. The layered structure embraces a wide range of layer dimensions with a difference in thickness of the tenth order (the most immense layer is the mantle, 2900-km thick)" (Kosygin, 1974).

I support such an understanding of the layered structure. It was precisely this conception that was approved in the second edition of the Russian Stratigraphic Code (1992), where a number of special units were suggested for usage.

Kosygin believes that "the recognition and description of the layered structure of the Earth form the basis for tectonic investigations" (Kosygin, 1974). Without objecting (though tectonics deals with deformations of the structure that the cited author emphasized), I should say that the layered structures, first of all those of the first order, (according to Kosygin), can be attributed to the subjects of stratigraphy. Let us consider this point.

Stratigraphic investigations comprise two main operations: (1) the subdivision of the section accompanied by characteristics of its intervals, i.e., stratigraphic units, with substantiation of their boundaries; and (2) stratigraphic correlation by substantial criteria (in a wide sense, including different geofields and energy potential) and/or by temporal factors (time of formation and position in the section) tracing the boundaries between different, including separated units.

A general subdivision of the Earth's subcrustal section with the help of different remote methods (using parameters of magnetic and gravitational fields of the planet, seismic and other data) can be conducted not only for the whole lithosphere, but at least for the upper mantle as well (*Geodinamicheskii* ..., 1989). Though the chosen conception or model plays a significant role in that subdivision, nevertheless, the results of most investigations in general are compatible.

It is natural to ask, may we regard the boundaries between deep geospheres as stratigraphic? Apparently we may, as different units of the Earth's crust have different types of boundaries. For instance, the diastrophic, i.e., tectonoplutonic events, are used to mark the boundaries between the Precambrian units (including even

[2] By stratification I mean the act of distinguishing stratigraphic units in stratified structures.

Characteristics of stratified and unstratified geologic bodies

Fundamental principles of stratigraphy; peculiar features of geologic bodies	Stratified (layered) geologic bodies	Unstratified (unlayered) geologic bodies
(1) Agreement with fundamental principles of stratigraphy:		
Steno's principle	+	–
Steno's principle (Meien's interpretation)	+	+
Huxley's principle	+	–
Meien's principle	+	–
Principle uniqueness	+	+
(2) Mode and time of origin:		
The force vector relative to the Earth's center	centripetal (gravitation)	centrifugal (deep forces)
Occurrence of geologic bodies relative to the Earth's surface (geoid surface)	originally parallel	originally perpendicular (radiated)
Feasibility of determining the stratigraphic (temporal) boundaries	lower/initial and upper/terminal	upper/terminal
Feasibility of determining the time interval (duration) of geological body formation	+	–
Application of PBGS	+	–
(3) Application of stratigraphic and temporal units:		
Local units	+	partial
Regional units	+	?
General units	+	–
Geochronological units	+	+
Geochronometric units	+	+

those of the standard stratigraphic scale), and this is not confusing (*Geologicheskoe* ..., 1989; Salop, 1982).

The vague nature of chronological characteristics impedes a consideration of subcrust layers as stratigraphic units. However, we may rely here on another parameter, i.e., on the unit position in the section.

The recognition of substance types of deep geospheres and boundaries in between them on the basis of different characteristics (with the help of different methods) is a reliable method within the upper mantle, but less conclusive in the lower mantle. Both the subdivision of deep geospheres and correlation between their units are based on their position in the radial section of the Earth.

Thus, if we even conditionally agree with the presented considerations then we are dealing with a trend in stratigraphic investigations similar to the stratigraphy of deep geospheres. The huge thickness of these planetary units is their qualitative and at the same time quantitative parameter. In the future, further subdivision of these section units into intervals exceeding units of the Earth's crust by thickness appears feasible.

4. STRATIGRAPHIC SPACE

Following from the above said, apart from the standart stratigraphic units, we implement the units special type as well as the concept of the layered structure of deep geospheres. Consequently, we may distinguish three major directions in stratigraphic studies: classic stratigraphy, specialized stratigraphy, and the stratigraphy of deep geospheres or geosphere stratigraphy. What are the links between them? Is it sufficient to relate them in a certain way and combine them in unitary stratigraphic space? Are they really antagonistic (especially the first and second directions)? Do their

units correspond to the definitions presented at the beginning of the article?

We can answer the last question affirmatively, since the spatial-temporal relationships can be defined both by revealing the forming sequence of the units and by fixing their position in the section. The last demand is satisfied in the context of special seismostratigraphic units, and on the other hand, in subcrustal geospheres, though, for various units the formation sequence is problematic or undefinable.

I came up with an answer to the first questions (curiously enough) while listening to the Leningrad Philarmonic perform Hindemith's symphony "Harmony of the World." The symphony is associated with the opera of the same name dedicated to Johann Kepler, who wrote the treatise "Harmony of the World" (1619), in which he tried to theorize laws ruling the universe and music. In the symphony, the composer digressed from the thematic substance of the opera and entitled three parts according to three categories of music suggested by the Roman philosopher A. Boetius of the VI century (about 480 - 524 A.C.) in the treatise "On Music." These categories are "Musica Instrumentalis" (music of instruments), "Musica Humana" (music of humanity), and "Musica Mundana" (music of the Cosmos or Universe).

And I thought that the attempt to divide stratigraphy into several "stratigraphies" by the applied methods (litho-, bio-, rhythmo-, magnetostratigraphy, etc.) is similar to the "Musica Instrumentalis," in which every instrument plays its own part independent one another. The methods of specialized stratigraphy plays the part of an instrument. But, in the same way that a listener perceives the orchestra in one sounding (if none of the instruments plays solo) in a manner differing from the perception of individually sounded instruments, a geologist understands the stratigraphic unit as an integrated geological body, in the breadth of all its evolutionary components: the litho-, bio-, hydro-, atmo- and other terrestial and cosmic processes, i.e., a body of the geosystem. Just as "Musica Humana" combines our "spiritual and somatic being," subjectivity (a personal element) assists us in classic stratigraphy much more than in specialized one. I consider it a merit rather than demerit, because in such a way one experiences the integrated interpretation of a natural object.

If we continue our discourse we may deduce the following conclusions:

(1) The two principal tendencies (conceptions) of stratigraphic classification and, virtually, two major sections of stratigraphy are not antagonistic. Each of them seems to be substantiated theoretically and proven by practice. A geologist, when studying a stratigraphic section, perceives its units as integrated geological bodies that differ from the other units through a series of characteristics. Some characteristics can be detected visually, or with the help of special instruments in the field, whereas others need laboratory treatment of the field material. At the same time, "subdivision" of stratigraphy according to research methods ("instruments") helps to reveal the importance of every method, its efficiency, and prepares the grounds for computer processing and so on.

Special principal and stratigraphic units comply with fundamental principles of stratigraphy and to all peculiarities of sheet-like (layered) geological bodies, which were listed above.

(2) Deep geospheres appear to be difficult to subdivide (they may be figuratively compared to the "Music of the Universe"). Their peculiar features seem to have no principal character with regard to stratigraphy. Yet possible subdivisions correspond to the definition of some special units adopted in the Code, and, to my mind, fundamental principles of stratigraphy can be applied to them, though with certain stipulations. Among the latter, the chronologic aspect is of lesser importance (at least, with our present knowledge of deep-seated structures of the Earth). It seems that ideas on the stratification of deep geospheres will develop upon application of different methods using both substantial and energy characteristics of layered structures, and, possibly, cosmogonic data. Still, these problems require special consideration.

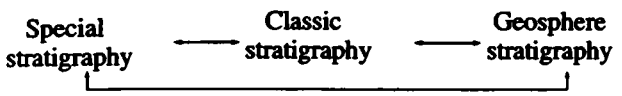
(3) At this time we can discuss relations between special and geosphere stratigraphies. A series of remote methods detecting different characteristics of a substance and geofields is in use now or may be applied in the future in the study of both the outer and inner geospheres. At least one of the categories of special stratigraphic units incorporated into the Code, the seismostratigraphic category, has been used to study the deep-seated strata.

The relations between classic and geosphere stratigraphy are close. The integrated object of the first, the layered structures of the Earth's crust, is a part of the upper lithosphere. Yet, in the framework of geosphere stratigraphy, the Earth's crust should be considered as a whole, or in terms of its greater units. At the same time, classic stratigraphy deals with general (even planetary) stratigraphic units within discrete geospheres of lesser thickness even if they correspond to geological systems (Zhamoida, 1980).

Deep geospheres (including the Earth's crust as a whole) representing thick and integral planetary structures or geostratigraphic units, incorporate all geologic bodies that constitute them or intrude into them. So, when considering the Earth's crust or a major interval of its section as an integral geostratigraphic unit, we should include both layered and originally unlayered geologic bodies into them, i.e., the stratigraphic section of the Earth's crust is in fact a section of geologic type. So I would denominate geosphere sections as geostratigraphic.

Returning to the second problem considered in this work, I should say that the geostratigraphic units embracing intrusives, dikes, and highly metamorphosed bodies, i.e., the primary unlayered formations, are subjects of geosphere stratigraphy, but not of the classic branch.

(4) Classic stratigraphy is central among the branches of stratigraphy. Owing to its and other sciences achievements, we now have "specialized stratigraphy" and "geosphere stratigraphy." The general organization of stratigraphy can be represented by the following way:



Geologic time links classical and special stratigraphy and their divisions. In practice, we realized these links in a form of the standard (general) geochronological scale supported by geochronometric data. The latter relate the above branches of stratigraphy to geosphere stratigraphy as well.

In every branch of stratigraphy, chronological information plays a different role. It is of most, or sometimes of primary, significance in classic stratigraphy, and has different meanings for different categories of special stratigraphy, but so far it is of no vital importance in geosphere stratigraphy.

(5) There are several definitions of the stratisphere. The stratisphere can be considered as a geosphere with recognizable stratigraphic units, or a space where stratification can be detected by any available method. The definition of the stratisphere as a geosphere comprising mostly layered structures of primary and secondary origin seems more acceptable to me.

If we accept any of the two presented definitions and admit the triad of major stratigraphic branches, then the space, or the world of stratigraphy will be much greater, that is, the stratisphere will comprise the entire lithosphere and, at least, the upper mantle as well. From this viewpoint, we need to define our science more precisely, and to clarify its problems as well. But this has to be discussed elsewhere.

Considerations suggested in this paper require further research efforts but seem to have great potential in principle.

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What Is Stratigraphy?

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Abstract – Stratigraphy, as a branch of geosciences, establishes a sequence of the origin of geological bodies in the stratisphere (the sedimentary shell of the planet). A stratigraphic investigation includes three stages aimed at subdividing particular sections: the recognition of the elementary stratigraphic units of a section, their correlation, i.e., the leveling of similar sequences in natural geological regions, and the determination of their sequence position in the stratisphere. Geochronology, a derivative of stratigraphy and based upon its data, studies geological time, while geochronometry is dedicated to measuring it. The most important goal of stratigraphy and geochronology is the determination of geological time with regard to lacunae (hiatuses) in the stratigraphic sequence.

"Although the stratigraphy is oldest among classic geological investigations and is widely used in practice, its subject matter and problems, from the viewpoint of *a specific division of geology*, remain unclear and disputable" (Leonov, 1973).

The reasons for this situation in stratigraphy are varied, and have resulted in the generation of many "stratigraphies" (Naidin, 1984; 1989). Stratigraphy's lack of a strictly defined subject and goal hampers elaboration of its theoretical basis, essential for any science. Attempts to establish personal laws in stratigraphy (similar to Ohm's, Boyle's, or Mariotte's laws in physics) so far seem premature. One may agree with B.S. Sokolov's note that among "the laws of stratigraphy, as they are called, there are probably only few that have universal significance" (Sokolov, 1991).

THE DEFINITION OF STRATIGRAPHY AND STAGES IN A STRATIGRAPHIC STUDY

Amid many definitions of stratigraphy, I prefer the one suggested by B.M. Keller (1976): "The stratigraphy (Latin *stratum*, the bed, to spread out, and Greek *graphein*, to write) is a branch of geology studying the sequence of the origin of geological bodies and their original relations in space."

As is known, we use three stages to determine the succession of the formation of geological bodies (Fig. 1). The first one is the dismemberment of a particular section (not in the sense of an outcrop), i.e., the recognition of its elementary stratigraphic units (beds, members, etc.) that differ in their features identifying first those, that do not repeat vertically.

The second stage is comparison, the leveling of similar sequences from separated outcrops of geological provinces (regions). The paleobiogeographic zoning is most significant when the comparison is based upon organic remnants. As a result we obtain a stratigraphic scheme for a part, or for all of the deposits in the province (region).

In stratigraphic practice, such comparison is usually termed correlation. From a variety of viewpoints, L.Sh. Davitashvili (1939) and O. Schindewolf (1950) argued against the usage of the term correlation in stratigraphy. In contrast, W. Arkell (1957) noted that, in a sense of stratigraphic leveling, R. Murchison used it even in 1849, the word "correlation" in stratigraphy does not correspond exactly to the sense of the word.

From a modern English-Russian dictionary we learn that the word correlation is translated as interrelation, or correspondence. An encyclopedia informs us that in science the word correlation (Latin *correlatio*, the relation) means interdependence, correspondence, or a relation of ideas, subjects, and functions.

It is clear that in correlating (i.e, comparing), for example, the Devonian of England and Kazakhstan, we mean neither their interrelation, nor interdependence according to the above definition. Now, it is hardly reasonable to argue against the use of this deeply rooted term in stratigraphy. We have to simply agree that the word "correlation" assumes something of a different connotation in stratigraphy, and that the Russian language is not less meaningful than English. Still, I have to note that G.P. Leonov (1974), our acknowledged authority in stratigraphy, used the term "stratigraphic paralleling" instead of correlation.

Nevertheless, the usage of the term correlation is sometimes inaccurate. Often (unfortunately, very often) we may read (particularly in titles of publications): "stratigraphy and correlation of deposits, or regions." First, it is illogical to use two terms of different system levels in the above combination. Stratigraphy is a science, while correlation is a step, phase, or stage in a study. The above word combination is senseless as correlation generates our ideas on the stratigraphy of certain deposits within a region. All stratigraphic ideas (on a stage, zone, formation, horizon etc.) were elaborated, and act in space as a result of correlation. In fact,

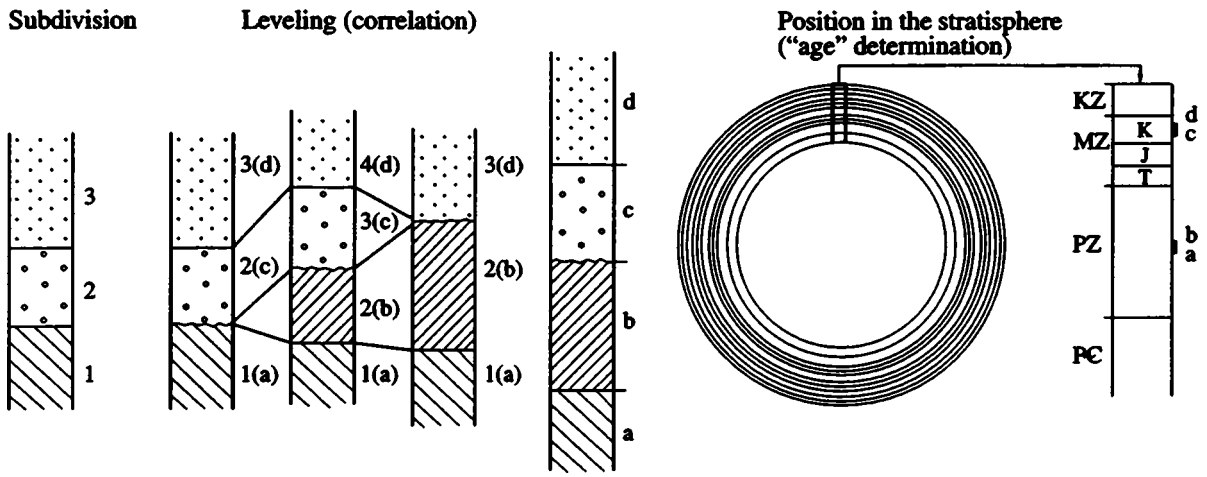

Fig. 1. Stages of stratigraphic investigation.

it is impossible to restrict stratigraphy to the dismemberment of a single section.

The spatial aspect of stratigraphy was most clearly manifested in recent years because correlation techniques progressed and especially as a result of achievements in seismic methods that enable continuous tracing in a lateral direction. A new branch, *sequence stratigraphy* appeared to operate with successive sedimentary complexes, i.e., with sequences of genetically related beds, members, and series, which are separated by unconformities and corresponding boundaries of concordant beds (Christie-Blick, 1990; Vail *et al.*, 1987).

The third stage in stratigraphic investigation is aimed at placing recognized stratigraphic units of a region into the general sequence of the stratisphere (the sedimentary shell of the planet), which is to say, an "age determination" from the viewpoint of geology. More precisely, it means ranking stratigraphic units according to the general (international) stratigraphic scale, the integrated stratisphere section compiled by generations of geologists.

It is known that this procedure requires the tracing of marks left by irreversible processes. In practice, these marks were produced by two types of processes: the evolution of organic life and the radioactive decay of elements. It is precisely these two processes that supply each level of the stratisphere with indicators that do not occur above or below it. Let us consider a very simple, but illustrative problem: how do we figure out the position of member "a" in the stratisphere, when it occurs above an old granite batholith (Fig. 2)? We use either radiometric dating or paleontological data. It is precisely the paleontological data that constrained the "age determination" of a sedimentary series overlying the Precambrian of the African platform and other old structures.

Of course, we may use other criteria related to irreversible processes, such as the evolution of sedimentation, ecological systems, rock geochemistry etc. Yet, the significance of their individual marks in the sedimentary shell is still insufficiently understood.

Without a doubt, modern geologists are not obligated to carry on all three stages of stratigraphic study, as is evident in the case illustrated in Fig. 2. However, initiated by Nicolai Steno and William "Strata" Smith, and then continued by generations of geologists and paleontologists, these three stages exactly resulted in Edward Suess' idea concerning the stratisphere, and in the empirical generalization known as the International Stratigraphic Scale. This would have been impossible without regional stratigraphic studies, i.e., without second stage of investigations within large areas.

THREE COMMENTS ON THE DEFINITION OF STRATIGRAPHY

Very many (perhaps the majority of) definitions of stratigraphy include the concept of time in some manner: "Stratigraphy studies rock beds in relation to space and time;" "Stratigraphy classifies rocks according to the time succession of their formation," etc. S.V. Meien (1989) also suggested including time as a general category in this science definition: "stratigraphy studies *space-time relations of rock complexes* (or simply, geological bodies) *in the Earth's crust.*"

The definition of stratigraphy in the preceding section does not include time, or related terms (e.g., chronology, chronological). Still in this definition, the term *sequence* indirectly implies a time arrangement, which is an immanent feature of any geological section being expressed in vertical succession of strata. In geology, "below/above" always means "earlier/later."

A sequence is a real subject that one can observe and study in various ways, while geological time is an abstract notion, and has to be reconstructed using revealed stratigraphic successions. It is unreasonable to unite these two categories in a single definition of stratigraphy, as one of them is derivative of another.

"Time is a surprising phenomenon. Its essence is unknown, but we are oriented in time because it is measurable" (Gumilev, 1992).

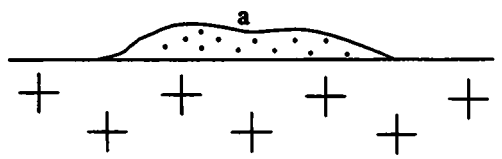

Fig. 2. Member "a" overlying ancient granite may find its level in the stratisphere according to marks left by irreversible processes.

The study and measurement of geological time are subjects of *geochronology*, a daughter branch closely related to stratigraphy and based upon its data. As far as a person is simultaneously a stratigrapher and geochronologist, the scientist studies the stratigraphy of the Devonian *system* and at the same time investigates the paleogeography of the Devonian time *period*. It is impossible to separate one from another because paleogeographic data is necessary for any reliable correlation.

In historical geology, for example, geochronology has to study the history of the Devonian period using stratigraphic data on the Devonian system. One may expect that stratigraphy and geochronology will be more differentiated in the future because of the differences in their methods. Even now, it is likely that geochronometry (in particular, radiogeochronometry) is diverging from geochronology, as this branch requires specialists of other sciences.

Above, we supposed that time could be estimated using stratigraphic sequences. This statement is not very precise since a sequence may be uncompleted.

"Lacunae in sedimentation are the least studied subjects of stratigraphy. This is quite understandable. Stratigraphers used to study deposits, or sediments, and did this satisfactorally. Still, often we have no deposits corresponding to hiatuses. We then need to investigate phenomena that are extraneous to stratigraphers, and they are simply unable to study such things. However, the pertinent number of minor and important problems is significant" (Nalivkin, 1974).

Amid many problems, two are of general significance: how to recognize lacunae in sedimentary series, and how to figure out their duration. According to Nalivkin's appraisal, only ten per cent, by time, of the Phanerozoic history is represented by deposits, or documented, as we may say.

In studies on ethnic history, L.N. Gumilev refers often to the experience of historical geology. The concluding chapter of his latest book (Gumilev, 1992) is titled "Chronosophy." The term means the description (chronography) of historical time. First, such a description should be of a corresponding time scale, and account for the adequacy of individual epochs, as "near to perfectly completed pages, there are large lacunae" (Gumilev, 1992). Thus historical time is intermittent, and consists of certain time intervals saturated with events. Geological time is similarly intermittent, and its discreteness is particularly evident because of hiatuses. Second, ethnic chronosophy takes into consideration time changes of boundaries between ancient geographic provinces. In other words, as in historical geology, the time and place of an action, i.e., two parameters of historical process, are indivisible.

It is unreasonable to hasten the introduction of "geochronosophy" in our practice. Yet now is the moment to pay more attention in geochronology to geological time studies. Nalivkin was not absolutely right when he stated that stratigraphers, coming across an extraneous phenomenon, do not know the way to investigate it. It is, after all, stratigraphers who first study and comprehend geological time when they recognize stratigraphic hiatuses. Using methods of other sciences one may advance from stratigraphic to time hiatuses.

Let us take an example. From 28 continental and oceanic sections across the Cretaceous–Paleocene boundary, which were considered earlier as continuous, 22 proved to have one, or more hiatuses, according to micropaleontological determinations. Radiometric boundaries of studied intervals are 66.40 and 66.12 Ma. So, the corresponding time span is 380 ka, while individual hiatuses have durations from several hundreds to 180 - 230 ka (MacLeod and Keller, 1991).

Geological time is a sum of its hiatuses and filled intervals measured by geochronometry in sequences.

The second comment on the definition of stratigraphy concerns its position relative to intrusive rocks: are they subjects of pertinent study, or not? Many geologists will answer "no" to this question. But according to the above definition, the reply should be positive: the intrusive rocks, like all geological bodies, do enter the subject matter of stratigraphy.

Usually, concepts and methods of stratigraphy are thought to be useless in respect to intrusive bodies because this science is understood as describing strata, while the intrusive rocks are unstratified.

For a long time, however, the names of many sciences have been inconsistent with their modern contents. So, crystallography at present is not restricted to crystal descriptions, but also studies of the state of crystal substances. Petrography is likewise the science of subjecting rocks to a complete analysis, but not to a description only. In the same manner, modern stratigraphy is not limited to a simple description of strata.

It is remarkable that many sciences, studying subjects known to be unstratified, use the ideas and terms of stratigraphy. For example, the branch of onomatology, analyzing the historical succession in the origin of proper names, is termed stratigraphy (*Onomastika* ..., 1988). Some French historians describe history dividing it into separate levels, the strata, i.e., considering it as stratified (Ferro, 1986). These examples show that outside of geology stratigraphy is interpreted as the *science of sequences*.

Finally, it is reasonable to include intrusive rocks into the sphere of stratigraphic studies, because their eruptive counterparts are definitely the subjects of stratigraphy. There is no sense in separating extrusive

and intrusive rocks when we determine their position in the stratisphere.

The third comment on the definition of stratigraphy is a conclusion consisting of these short notes.

As defined by Keller, stratigraphy is a constituent of geology. It seems more correct to define it as an individual science among the Earth sciences. First, this science has its own subject, the geological bodies of the stratisphere (the uppermost part of the Earth crust), and its purpose, revealing the sequence of geological bodies formation, is clearly fixed. Second, despite using methods from various sciences, stratigraphy has a broad range of its own principles, some of which are applicable to other scientific branches.

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Solution to Basic Problems in Stratigraphy Using the Example of the Lower Cretaceous in Turkmenistan

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Abstract – Various groups and categories of stratigraphic units are involved in the solving of the problems of detailed stratigraphy. Their role is not the same within one region and in areas with different geologic structure. The specific, local, and biostratigraphic rock units are important in the subdivision of sections of stable sedimentation, whereas elementary, local, and regional units are used for correlative purposes. The role of regional and general stratigraphic units is more important in sections of unstable sedimentation.

Stratigraphy is a fundamental branch of geology, the principal task of which is to reveal the initial distribution of crustal layers in time and space, i.e., to study the Earth's matter at a super-rock level (Sadykov, 1974).

In spite of the tremendous achievements in stratigraphy in the last decades and the appearance of several new methods and means of research (seismostratigraphic, magnetostratigraphic, correlation of events, and others), its basic tasks remain unchanged, i.e., the subdivision of the sequence of layers in the crustal section and the correlation of layers (events) of identical (coeval) position in the lithosphere.

The principles suggested by Steno, Huxley, Smith, and Dollo were applied to reach the first goal, i.e., the discrimination of a definite stratigraphic unit by its specific features, the determination of criteria for its identification, and the establishment of its position in the section with respect to the overlying and underlying strata. In previous research, the analyzed data were concerned mainly with the differences in the composition and texture of the rocks, or in organic assemblages. Nowadays, this information is supplemented by comparatively detailed lithologic and paleontologic descriptions of physical and chemical characteristics.

When studying a section (an outcrop or a bore-hole), the specialist, on the one hand, wishes to obtain as detailed a subdivision as possible and, on the other hand, to group the layers into units characterized by one or several common features. The latter effort is, in fact, the differentiation of concrete stratigraphic units, i.e., the common features and the degree of their similarity are used to form the units of different groups, categories, and ranks.

Both trends are illustrated well by recent studies of the Kopet Dag Lower Cretaceous deposits (Fig. 1). According to the studies in this area by V.F. Pchelintsev and G.Ya. Krymgol'ts (1934), V.I. Marchenko (1962), T.N. Bogdanova and S.V. Lobacheva (1966), K.N. Amanniyazov *et al.* (1987), and others, the lower part of the Cretaceous System is divided into numerous elementary units-beds differing in composition, color, structure, texture, and other characteristics, including the degree of difference in lithology and the clarity of boundaries between the layers. In accordance with the purposes and scale of the study and the personal aims of the researcher, the layers are distinguished by different parameters, and the same section may contain a different number of layers. In other words, in the studied section, a layer is the elementary observation unit of a rather arbitrary definition. Though the layers have their own peculiarities, every subsequent researcher tries, through subdivision, to increase the number of layers and the details of their description.

After the identified layers are described, they are grouped into different combinations, which may serve as instruments in using the section for certain purposes. The selection of features for such combinations is also arbitrary and depends on the tasks, purposes, and scale of study, and on the disposition of the researcher, i.e., the scope of his experience and training, theoretical preferences, and so on. There is a general tendency, however, to single out the units on a larger scale, which results in still slighter connections between the determined stratigraphic units and a concrete section. In fact, the verification of their presence demands more thorough proofs. This is especially true of the boundary positions of the layers.

Thus, the elementary layers are combined first into groups by their lithology, determined by direct observation or by laboratory analyses. The given example (Fig. 1) illustrates this stage in the study of the section by distinguishing a uniform member of a certain number of layers with a similar composition (Marchenko, 1962): pelitomorphic, oolitic, and clayey limestones, those with rudists and other kinds of limestones, marls, clays, sandstones, and other rocks. The boundaries of these specific units, according to the Stratigraphic Code (*Stratigraficheskii Kodeks*, 1992), are fairly definite, distinctly observed in outcrops, and in most cases can be detected by logging. Nonetheless, the definition of

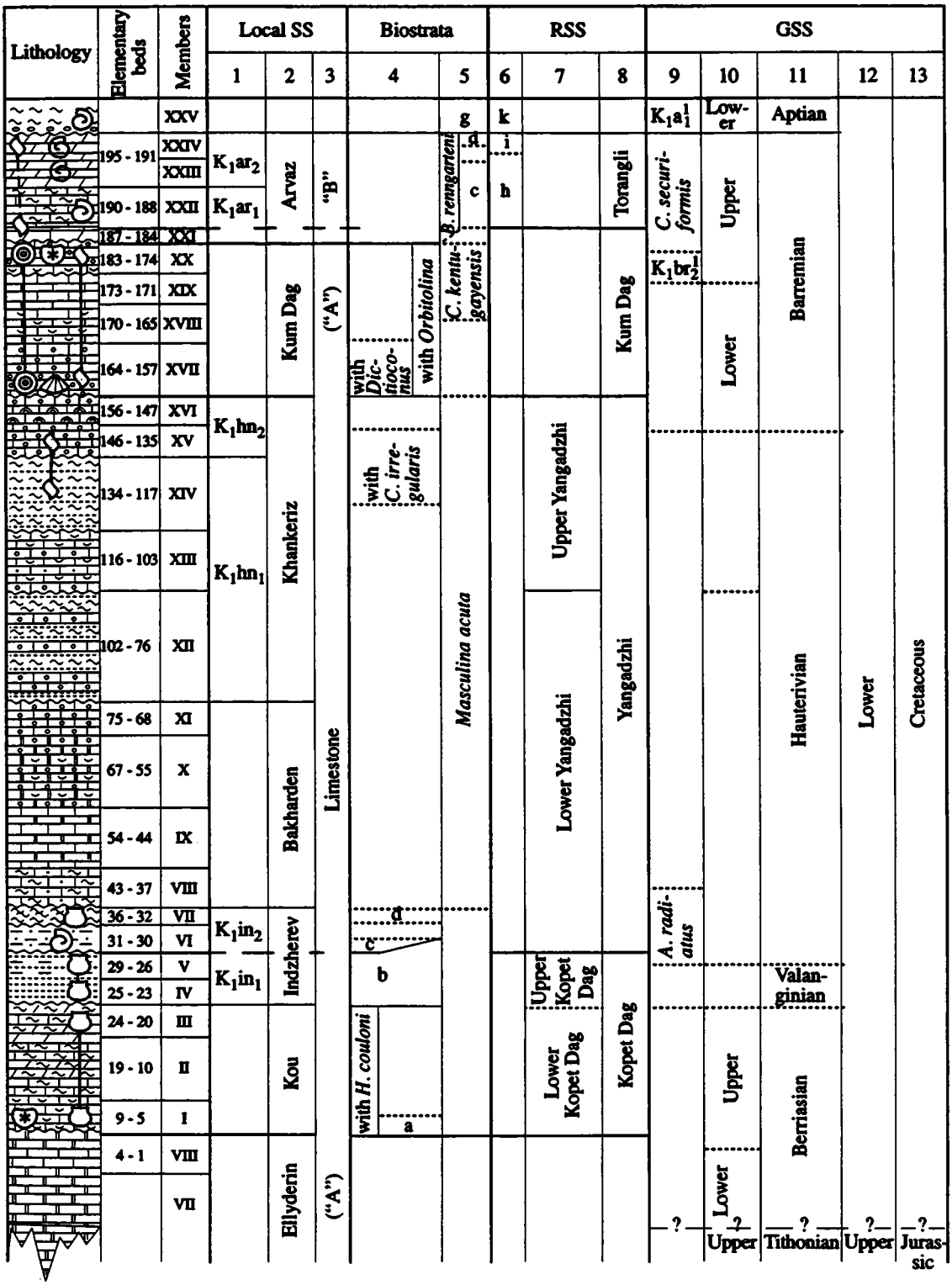

Fig. 1. Subdivision of the Lower Cretaceous section near the underground Kou Lake in the central part of Kopet Dag.

1 - 3 – Units of the local stratigraphic scale: 1 – sub-formations, 2 – formations, and 3 – groups; 4, 5 – units of biostrata: 4 – layers and 5 – biostratigraphic zones; 6 - 8 – units of the regional stratigraphic scale: 6 – provincial zones, 7 – subhorizons, and 8 – horizons; 9 - 13 – units of the general stratigraphic scale: 9 – chronozones, 10 – substages, 11 – stages, 12 – series, and 13 – systems. Biostrata: a – beds with *Toxaster granosus*; b – beds with *Exogyra* and *Lima*; c – beds with *Endemoceras*; d – beds with *Pholadomya minuta* and *Ph. gillieroni*; e – beds with *Imerites* and *Colchidites*; f – beds with *Turkmeniceras turkmenicum*; g – beds with *Deshayesites tuarkyricus*. RSS: h – *Imerites* and *Colchidites* local zone; i – *Turkmeniceras turkmenicum* local zone; k – Deshayesites tuarkyricus local zone. See Legend to Fig. 2.

lithological members is to a great extent subjective. Thus, they can be determined only by an essential difference in the composition of deposits, by the facies-genetic peculiarities, cyclicity (often differently interpreted), inclusions, and so on. A combination of different member differentiation principles can be applied as well, i.e., in terrigenous rocks using their mineral composition, whereas in carbonate rocks using structural features. And yet, this stage of study is extremely important, because it reflects more objectively than the previous one the compositional differentiation in the structure of the section and readies the observation material, partly analyzed, for all kinds of generalizations.

The next stage in the study of the section is the consecutive reference of units to different categories of principal stratigraphic subdivisions (*Stratigraficheskii Kodeks*, 1992). The local units can be determined in a concrete section. Thus, if a certain lithologic feature dominates in the observed members, then the latter are joined into a certain number of sub-formations and formations (more likely, first, into formations and then into subformations as, perhaps, V.I. Marchenko did for the carbonate rocks of the Kopet Dag). The formations constitute a more definite rock association, showing the distribution of rock peculiarities in the section of a certain area. The position of the top and base of the formations is determined by material evidence. For example, the prevalence of clearly stratified black and dark gray carbonate-clayey rocks is a criterion for the Kou Formation. Its base coincides with the bottom of those rocks overlying with erosional unconformity the massive light-colored carbonate rocks of the Ellyderin Formation. The top of the Kou Formation corresponds to the erosional surface at the base of the greenish-gray calcareous sandstones of the Indzherev Formation. And still, there is a certain subjective approach to the definition of the main units on a local scale and of their boundaries in particular. This is true not only of more or less gradual transitions from one formation to the other, but of the very principle of identification of a formation by its composition, cyclicity, inclusions, and so on. Distinct discrimination of a formation in a concrete section depends on several factors: the reliability of its diagnosis by previous researchers, if the subdivision into formations has already been made, the quality of a chosen stratotype and the completeness of its description, and the clarity of boundary criteria. The Mesozoic Kugitang, Gaurdak, and Karabil' formations in the southwestern foothills of the Gissar Range can serve as an example of the variety and ambiguity in the determination of the stratigraphic volume of the formations and of the position of their boundaries. The controversy that surrounds their definitions by different specialists is the result of an insufficient initial description and by a lack of rigorous lithologic criteria (Miroshnichenko, 1933; Kheraskov, 1934; Kalugin, 1953).

Presently research tends to divide the section into smaller elements, though the rank of these stratigraphic units is likewise determined empirically (*Stratigraficheskii Kodeks*, 1992; clause V. 5). Thus, many formations become groups, subformations are called formations, and members are defined as subformations.

The stratigraphic studies described above analyze the lithological peculiarities of the section, but the subdivision of sections by paleontologic data is, perhaps, no less popular and successfully applied (Bogdanova and Lobacheva, 1966; Lobacheva, 1991). Thus, the identified biostratigraphic units should include, apparently, only those deposits containing the analyzed fossils, which shows an essential difference between the units distinguished by lithologic and paleontologic evidence. The lithologic units always build up the entire section of the locality, and their position is in fact permanent, with the exception of their ranking. The biostratigraphic units in the section, however, have a sporadic distribution with more or less obvious gaps. The position of the boundaries and of the units themselves are shifted according to new finds of fossils or new data on their taxonomy. Nonetheless, biostratigraphic units are an important, necessary, and independent means of subdividing the section, because the units identified by fossils are sufficiently distinct, particularly in areas of stable sedimentation. This is one of the reasons why they should be included, at least partly, in the category of local stratigraphic units.

In concrete sections, the definition of the units of both the regional stratigraphic scale (RSS) and the general stratigraphic scale (GSS) can be obtained conducting special paleontologic and lithologic laboratory analysis and by correlation of the studied section with other sections, unless the studied section is a stratotype. Indeed, the criteria for RSS and GSS strata, if reasonably distinct, allows us to detect their presence in a section more or less reliably. For example, the section near the underground Kou Lake (Fig. 1) is a stratotype of the Kopet Dag Horizon and contains other horizons and local zones of the pre-Aptian Cretaceous deposits of Turkmenistan. The principal criterion for the Kopet Dag Horizon is the presence of Berriasian–Valanginian fossils in its rocks. In this section, the Kopet Dag Horizon corresponds to the Kou Formation and two and a half members of the Indzherev Formation (IV, V, and the lower part of member VI). The base of the section coincides with that of the Kou Formation, and its top corresponds to the base of the beds containing Lower Hauterivian ammonites. In the stratotype, the horizon can be divided into subhorizons, whose boundary corresponds to that between the formations. The criterion for drawing the latter is the presence of principally Berriasian fossils below the boundary and of Valanginian fossils above it.

The overlying Yangadzhi Horizon includes the upper part of the VI and VII members of the Indzherev Formation and the entire Bakharden and Khankeriz formations. The lower boundary of the horizon corresponds to the base of the beds containing *Endemoceras* (Luppov and Prozorovskii, 1983) of the Lower Hauterivian; its top lies at the bottom of the overlying Kum Dag Formation. The Yangadzhi Horizon in this section

can also be divided into two subhorizons; the boundary between them lies approximately at the base of the thirteenth member of the Khankeriz Formation and divides two faunal benthic assemblages, common in this area, into the lower, mainly the Lower Hauterivian, and the upper, the Hauterivian-Barremian.

Above these strata, the Kum Dag Horizon is reliably identified; here it coincides with the Kum Dag Formation and the lower member (XXI) of the Arvaz Formation. Its upper boundary is largely tentative because of the paucity of ammonites in the upper layers.

In this section, the overlying Torangli Horizon is also tentatively determined, covering a stratigraphic interval from the top of the XXI member to the base of the Aptian local zone of *Deshayesites tuarkyricus*. Single finds of ammonites, which are the criterion for distinguishing the horizon here, only confirm its presence and the zones composing it. The position of both boundaries of the horizon in the Kou Lake section is not justified.

The determination of the GSS units in this locality is even more complicated. The presence in the section of certain characteristic forms of bivalves, brachiopods, echinoids, foraminifers, and rare ammonites implies the Berriasian, Valanginian, Hauterivian, and Barremian stages. The Hauterivian substages, the Upper Barremian, and its upper zone can also be identified. As yet, their boundaries and the corresponding local subdivisions are not determined. There is no proof of the position of boundaries between the GSS units. A number of authors (Amanniyazov *et al.*, 1987; Lobacheva, 1991; Marchenko, 1962) suggest their concurrence with the lithological boundaries, but, I think, this only discredits stratigraphic schemes.

The relatively complete and well studied Lower Cretaceous Kopet Dag section near the underground Kou Lake can be subdivided into stratigraphic units of different groups and categories. All of them are independent and differ in volume (*Stratigraficheskii Kodeks*, 1992; clause II.6). In the concrete section, special, local and biostratigraphic units are reliably and simply determined. The discrimination of the RSS and particularly of the GSS units is not always possible.

The second problem in stratigraphy is correlation, whose solution is universally understood as the definition of stratigraphically uni-volumetric (synchronous) deposits within the studied area and ideally, on a planetary scale[1]. This procedure is based mainly on the principles set up by Smith, Gressly, Renevier, and Huxley. The process of correlation itself follows the principle formulated by Meien in 1974, which he called the principle of reciprocal substitution of features, i.e., "the chronologically identical or reciprocally substitutable are stratigraphic characteristics reflecting the traces of one and the same reorganization of the geosystem, even on a planetary scale. This principle provides for the establishment of chronological levels" (Meien, 1974).

Apart from the criticism of the formulation itself, I completely agree with Meien that the comparison of real sections for the purpose of establishing coeval intervals in them should be based on the analysis of concrete stratigraphic characteristics, generally lithologic or paleontologic. It is quite obvious that the stratigraphic importance of these characteristics differs, and they should be well "assessed" to insure reliable results.

Figure 2 shows an example of how a combination of the study of numerous changes in the Lower Cretaceous deposits with the integrated research of many years yields, as I believe, a sufficiently complete description of this process.

The supplementary stratigraphic units (members), identified in concrete sections, and individual layers with a specific structure provide important evidence for correlation mainly within a certain type of section. The most widespread strata with the most stable and consistent characteristics can also be used to compare adjacent sections, thus expanding into their localities. In our study, the member of evaporite rocks with concretions and lenses of celestine, gypsum, and barite is an excellent example of a key bed. It is deposited in the middle (the third member) of the Yangadzhi Formation of the Kubadag Range, at the base of the Tuarkyr Formation in southern Tuarkyr and in the central part of Kara Kum, at the base of the Kyzylkyr Formation in northern Tuarkyr, and even in the middle part of the Kugusem Formation in the Mangyshlak Mountains (Prozorovskii, 1991). This key bed alone provided the correlation of extremely variable and actually fossil-free deposits of red rocks in this vast territory.

However, the lithologic characteristics are not always stratigraphically informative, as illustrated by the seventh member of the Indzherev Formation in Kopet Dag. It is a layer of clayey rocks 25 - 30 m thick, deposited at the base of the carbonate Bakharden Formation and distinctly identified in outcrops and by logging. These rocks contain abundant shells of pholadomyas, a fact that allowed T.N. Bogdanova and S.V. Lobacheva (1966) to identify them as a specific stratum with *Pholadomya minuta* and *Ph. gillieroni*. However, in the section near the Kou Lake (Fig. 1), the casts of the Lower Hauterivian *Endemaceras* (Luppov and Prozorovskii, 1983) were found along with these bivalves and at lower level, whereas, 80 km to the east, the Upper Valanginian ammonites of the *Saynoceras verrucosum* Zone were recovered from similar rocks.

Mesozoic material from Turkmenistan clearly implies the low correlative value of the local stratigraphic units. The boundaries of almost all formations either sharply cross over the age boundaries, or do not supply information that could correlate them. Strictly speaking, extensive general correlations cannot solely be conducted through lithologic similarities, which is a favorite approach of geophysicists. Often, using the physical properties of rocks and the boundaries that

[1] Synchronous (coeval) are events (deposits) projected by the researcher onto the same division (interval) of the external scale (Meien, 1974).

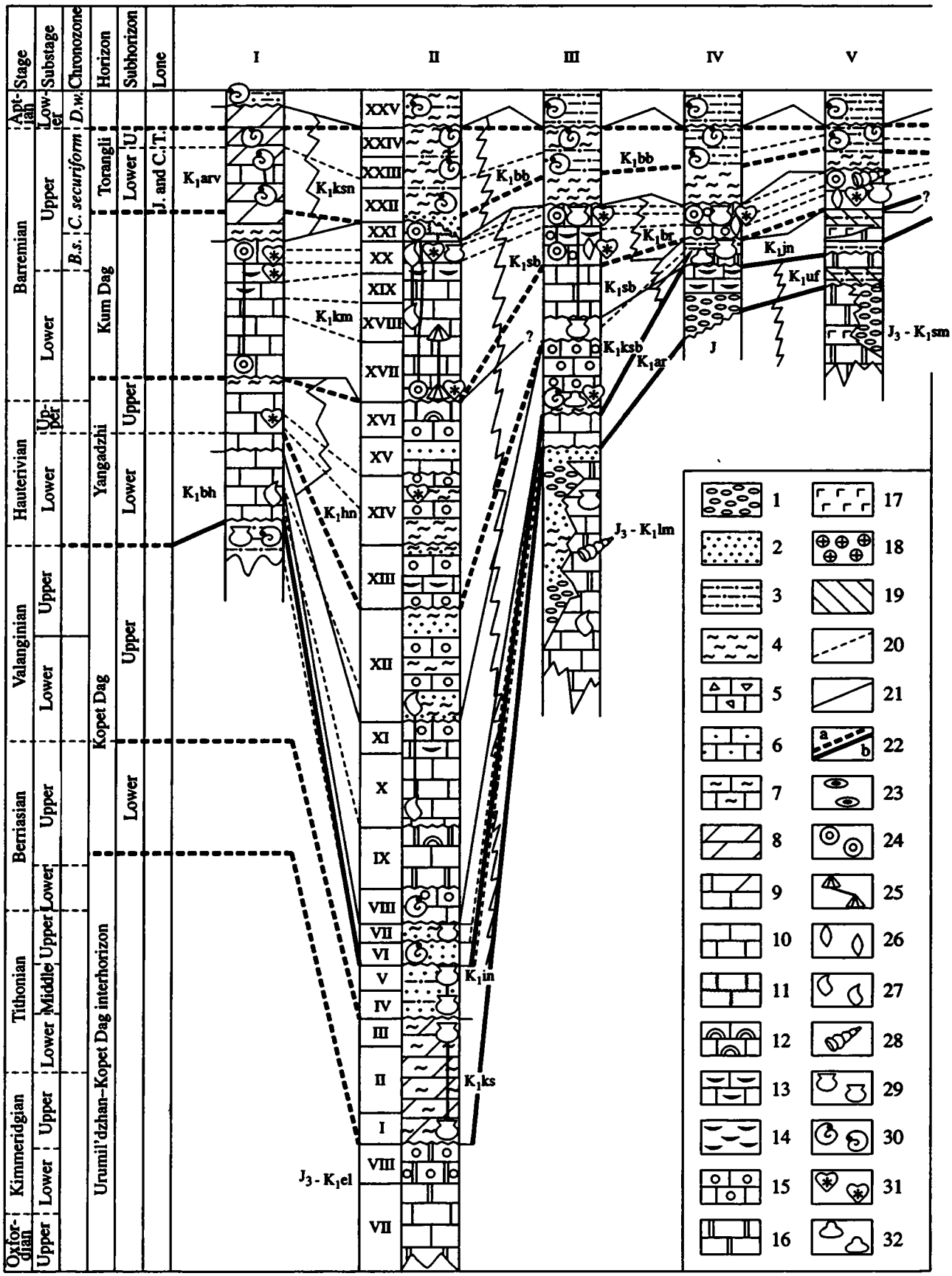

Fig. 2. Correlation of the Upper Jurassic and Lower Cretaceous deposits in the Transcaspian.

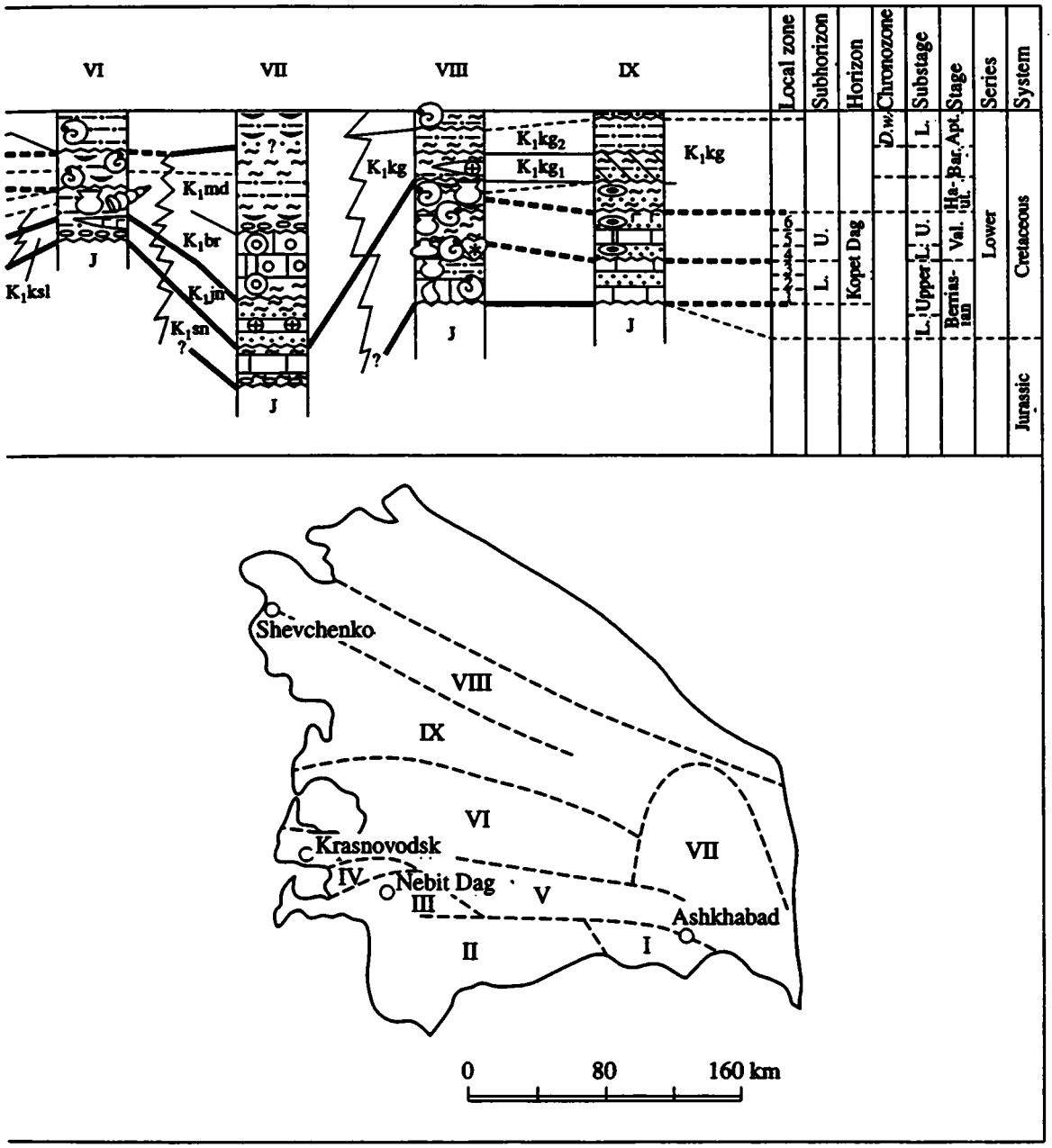

Fig. 2. (Contd.)

Types of sections: I – Ashkhabad, II – Kizylarvat, III – eastern Bol'shoi Balkhan, IV – western Bol'shoi Balkhan, V – Kybadag, VI – central part of Kara Kum, VII – Murgab, VIII – Mangyshlak Mountains, and IX – southern Mangyshlak.

1 – Conglomerates; 2 – sandstones; 3 – siltstones; 4 – clays; 5 – clastic limestones; 6 – sandy limestones; 7 – clayey limestones; 8 – marls; 9 – alternation of limestones and marls; 10 – limestones; 11 – reefal limestones; 12 – algal limestones; 13 – organic limestones; 14 – coquinas; 15 – oolitic limestones; 16 – dolomites; 17 – gypsum; 18 – celestine concretions; 19 – red-rock beds; 20 – boundaries of bio- stratigraphic units; 21 – boundaries of lithostratigraphic units; 22 – boundaries of regional horizons and subhorizons: a – paleontological and b – lithological; 23 – small foraminifers; 24 – orbitolinids; 25 – dictioconuses; 26 – balkhanians; 27 – brachiopods; 28 – gastropods; 29 – bivalves; 30 – ammonites; 31 – echinoids; 32 – ganoid fish teeth.

divide formations of different composition, they try to distinguish the GSS units (in actual fact, the formations) and draw their boundaries through comparison of qualitative levels. As a result, they lose or miss the intervals of distorted correlation, i.e., possible localities for non-structural traps. For example, members of the Geophysical Expedition in western Turkmenistan joined the carbonate rocks of five different stratigraphic volumes into one unit called "the Lower Barremian."

Biostratigraphic units have different correlative meanings; if a biostratigraphic unit is understood to be rocks with fossils. The units identified through representatives of the orthostratigraphic groups are extremely important. In the region and the stratigraphic interval of the example given above, they are too few to have any correlative value. But, of course, they are indispensable for dating the deposits.

In the subdivision by benthic remains, which dominate in the Lower Cretaceous carbonate red rocks of Turkmenistan, along with important correlation layers, such as those with *Tetragramma renngarteni*, with *Orbitolina*, with *Dictyoconus*, with *Pseudonerinea ornata*, and others, there are the biostratigraphic units whose position in the section may change. For example, the biostratigraphic zones, which Lobacheva identified by the presence of brachiopods, layers with *Turkmenia balkhanensis* and others can be referred to such biostratigraphic units. The age of the latter ranges from the Late Hauterivian in western Turkmenistan to the beginning of the Aptian in the southwestern Gissar and to the Latest Aptian and, probably, Earliest Albian in southern Afghanistan. Of course, the best correlative opportunities are provided by the zones with common boundaries, as, e.g., *Orbitolina delicata* and *Heteraster* zones, which cross lithologic boundaries and supply data for the justification of correlations within the entire southern and central areas of Turkmenistan.

RSS units are the most reliable means of correlating strata, whereas their boundaries are the main chronostratigraphic levels. In the studied region, the points where the lithologic or biostratigraphic units coincide are the "golden nails" of the boundaries of the horizons or local zones; they are used as the types of the identified RSS units. For example, the boundary between the Kopet Dag and Yangadzhi horizons is indicated by the points in the sections located near the Kou Lake and on Kazandzhaburun Mountain. In these localities, the layers of the Indzherev and Arlan formations with Berriasian–Valanginian or Valanginian fauna are overlain by layers with Early Hauterivian ammonites. Subsequent correlation is as follows: on Kazandzhaburun Mountain, the base of the layers with *Endemoceras* contains ganoid fish teeth also found at the base of the bioherm layer in the next section located 15 km to the northeast. Along its strike, this layer is substituted by terrigenous, partly red-colored rocks with lenses of evaporites. In the neighbouring structure of the Kubadag Range, the carbonate deposits with the Valanginian gastropods and brachiopods are overlain by a red-rock layer with lenses of gypsum, anhydrites, and single finds ganoid fish teeth.

Another example: the boundary of the subhorizons (the Yangadzh Horizon) in the Kopet Dag near the Kou Lake is confined by a change in faunal assemblages common to various Hauterivian substages. In the area of Bol'shoi Balkhan, this boundary correlates with the change of carbonate to terrigenous rocks and with the appearance of the remains of endemic bivalves *Turkmenia balkhanensis*, *Exogyra turkmenica*, and others. Further west, layers with celestine concretions correspond to this level.

In fact, individual boundaries are the stratigraphic reference levels for any concrete region, because they allow us to make relative chronostratigraphic correlations of different facies by applying, in this case, Meien's principle.

In general, correlation prospects using GSS units is minimal in regions with relatively complete sections and diverse facies that seldom contain guide fossils. Correlations by the "age" of deposits, often used in studies, as a rule result in errors, because the intervals of the section, assumed to be coeval, have absolutely different stratigraphic volumes. For example, there were attempts to correlate the Hauterivian (!) formations, i.e., the Kyzyltash Formation in the southwestern foothills of the Gissar Range with the Bakharden Formation of Kopet Dag, but the Hauterivian age of the former is highly debatable, whereas the latter, though most of it belongs to the Hauterivian, is only a part of the Lower Hauterivian substage.

To conclude, the most important role in a concrete region belongs to the elementary, supplementary, local, and regional stratigraphic units. In small-scale geologic research and extensive generalizations, GSS units are much more important. Moreover, the significance of units of various categories changes in regions differing from those analyzed above by lower facies variety, frequent finds of guide fossils, an incomplete section, and so on. For example, in the upper part of the Lower Cretaceous, in the Aptian and Albian layers of Turkmenistan, and in the terrigenous marine deposits rich in ammonites and inocerams, the GSS zones or the RSS local zones provide a more reliable and detailed correlation, though the units of other categories can be helpful in individual cases. Still, the role of the biostratigraphic method in comparison with the lithostratigraphic and other methods dealing with the physical properties of rocks is especially important for these kind of sections.

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Recognition of Finer Stratigraphic Units in the Neogene of Kamchatka

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Abstract – The subdivision of the Neogene strata in Kamchatka suggests that it is possible to recognize infrazonal units. On the basis of a bed-by-bed analysis of different paleontologic groups (diatoms, mollusks, and foraminifers) and the usage of paleomagnetic and other physical methods, 42 beds and 15 members with mollusks and 15 beds and 9 members with foraminifers are distinguished within 6 regional stages (formations). The estimated duration of the Pliocene stratigraphic units (0.03 - 0.09 to 0.12 - 0.35 Ma) corresponds to that of the Quaternary units. The recognition of finer stratigraphic units may be of great practical value in detailed geological mapping, paleogeographic reconstructions, and so on.

INTRODUCTION

Clarifying stratigraphic schemes is one of the most urgent problems in stratigraphy. Therefore, both the zonal and infrazonal subdivision of deposits has attracted the steady attention of geologists. Finer stratigraphic units are necessary for large-scale geologic mapping and the reconstruction of short-term paleogeographic events. This can provide both broad correlations and environmental forecasting for future centuries. Unfortunately, the materials on recognition of finer stratigraphic units in the Russian regions differing in geological history has been accumulated and interpreted on a limited scale. However, the following groups of these units have been distinguished (Menner and Gladenkov, 1986): (1) paleomagnetic (orthozone, subzone, and microzone); (2) lithostratigraphic (member, strata, and bed); (3) sedimentary-cyclostratigraphic and seismostratigraphic (cyclothems of different scale); (4) eustatic (transgressive and regressive cycles and eustaliths); (5) paleotemperature (optima and minima) and isotopic units based on the $^{18}O/^{16}O$ ratio (isotopic stages); (6) paleopedological (groups, horizons, and particular fossil soils); (7) climatostratigraphic units of the Quaternary (division, link, step, stage, stadial, and oscillation); (8) biostratigraphic (biozone, ecozone, epibole, teil-zone, beds with fauna, datum-planes, and interdat). Although these groups of units have been sufficiently characterized in the publications referred to, some recent articles describe a detailed procedure for recognizing finer microstratigraphic units. The best of them is the summary on the Frasnian of the northwest Russian platform (Sorokin, 1978). In different-facies sections over the large territory, the author distinguished beds with geographical names and members, which correspond to the sedimentary rhythms of IX and even X - XII orders.

The purpose of this article is to discuss the recognition of finer units in the Neogene of Kamchatka. This geological object is considered to be quite complicated. It is characterized by lithofacies diversity, hiatuses, and a great strata thickness, which were formed in the active Asian margin. Nevertheless, the researchers from the Geological Institute, Russian Academy of Sciences, have recently obtained some promising results.

In the late 1970s - the mid-1980s, an attempt was made to distinguish both zones (by means of diatoms and other fossils) and finer units – beds with fauna (mollusks and foraminifers) – in the Neogene formations of the Tochilin reference section of west Kamchatka (*Atlas fauny* ..., 1984). The beds with mollusks were traced for a distance of 700 to 800 km in a longitudinal direction through Kamchatka (Sinel'nikova, 1988). Similar beds with mollusks were distinguished in the Oligocene to Middle Miocene of the Korf Bay in east Kamchatka (Gladenkov *et al.*, 1987).

The beds were recognized by the following characteristics: the total number of species in a unit, the number of predominant and first appearing forms, the relationship between extinct and living species, the relationship among various paleoecologic and paleobiogeographic associations, the percentage of endemic forms and widespread species, and the ages of individual species and assemblages (Gladenkov, 1988).

The accumulated observations and data were used to subdivide the Neogene reference section in Karaginskii Island, east Kamchatka. The present publication is concerned with this subdivision.

PARASUBDIVISION AND INFRAZONAL UNITS OF THE NEOGENE OF EAST KAMCHATKA

The Karaginskii section has long been studied by researchers from the Geological Institute, Russian Academy of Sciences. Results of the studies were summarized in a special monograph (Gladenkov *et al.*, 1992).

The Neogene of this region includes a number of formations (stratigraphically upwards) (Fig. 1): Lower(?)–Middle Miocene – the Variegated Formation (tuffstones, siltstones, 380 to 425 m thick); Middle-Upper Miocene – the Mys Ploskii Formation (siltstones, diatomites, 685 to 775 m thick); Upper Miocene – the Yunyun'vayam Formation (diatomites, sandstones, 300 - 330 m thick); Pliocene – the Limimtevayam Formation (conglomerates, sandstones, 290 m thick), Ust'-Limimtevayam Formation (sandstones, more than 80 m thick), and the Tusatuvayam Beds (more than 20 m thick).

These formations show some distinctive lithologic strata and members [numbered in Fig. 1 after Gladenkov (1972)]. A bed-by-bed sampling of these strata produced abundant faunal and floral remains, which were studied by K.B. Barinov (mollusks), S.I. Bordunov (foraminifera), T.V. Oreshkina (diatoms), D.I. Vitukhin (radiolarians), G.M. Bratseva, and E.V. Zyryanov (spores and pollen). I performed a synthesis of the data obtained. Paleomagnetic records (V.M. Trubikhin) and isotopic age determinations (S.S. Ganzei) were used to date the Neogene sediments. Already in publication, these materials are omitted herein. This publication is concerned with the way in which the finer stratigraphic units were recognized.

Because the Neogene sediments of Karaginskii Island were accumulated on the continental shelf, their subdivision is based on the benthic assemblages (mollusks and foraminifers). In general, we used parasubdivision, but in cases where planktonic remains (with siliceous skeleton) and the benthic forms occurred concurrently, orthosubdivision was also used. Zones (or their parts) recognized by the plankton allow us to relate the finer parastratigraphic units to the oceanic scale and then to the standard scale. In general, the fossil content of the sections suggests two complementary ways to correlate them, which check each other: on the one hand, correlations between the Neogene stratigraphic levels of east Kamchatka – formations, horizons, local zones, and beds – and those of other regions of Sakhalin, Japan and North America by benthic forms and, on the other hand, correlations of planktonic zones. Any coincidence or discrepancy in the obtained results is subjected to special analysis. In case of coincidence, the correlations are considered reliable.

In our case, the correlation of the sedimentary strata was based on mollusks and foraminifers. Subdividing the section and dating the finer units consists of a number of operations. At first, concrete beds with fauna ("bed") were recognized in every formation. In some cases, these beds replace one another without a gap, in other cases they are separated by intervals lacking fauna (interbeds), i.e., they are contiguous to each other. Every bed was named, in general, for the species that determined the aspect of the bed, i.e., that were peculiar to it. Abundant species were taken into account as well. This approach considers a bed as a unit integrating biozones of some taxa and ecozones (epiboles) of others, permiting us to reliably recognize it. Practice shows that such beds with molluskan assemblages distinguished by peculiar and dominating forms are identifiable and traceable.

As mentioned above, the analysis of every bed with fauna was based on changes in the total number of species, a number of new species, a percentage of recent forms and warm-water species, and the number of endemic forms. Species (and their combinations) with a wide area of distribution and a limited age range drew special attention.

In total, 42 beds with mollusks (M) (23 in the Miocene and 19 in the Pliocene) and 21 beds with foraminifers (F) (13 in the Miocene and 8 in the Pliocene) were distinguished. So, the number of molluskan beds is twice that of the foraminiferal beds. The subdivision of the section shows that some beds are separated by thin interbeds free of fossils. There are 13 interbeds lacking mollusks and 7 interbeds lacking foraminifers. It should be noted that locally mollusk-free interbeds are substituted for beds F and foraminifera-free interbeds for beds M. Thus, beds M and F can characterize the entire section, except for small parts of stratum 13 of the Variegated Formation, strata 7 and 9 of the Yunyun'vayam Formation, and stratum 10 of the Limimtevayam Formation. But these parts constitute a very small portion of the section.

Then, beds M and F (with interbeds) were united into larger units – members with fauna. They are characterized by certain similar fossil assemblages, which reflect separate stages of biotic evolution, and by their relation to various sedimentary cycles, which often correspond to eustatic changes in the global Ocean level. We recognized 15 members with mollusks (I - XVM) and 9 members with foraminifers (I - IXF), which are coincident with each other in some places. So, IM corresponds to IF, IIM to IIF, IXM to VIF, X and XIM to VIIF, XII and XIIIM to VIIIF, XIV and XVM to IXF. That is why the members with complex polytaxa characteristics (M and F) are distinguished. They are of great practical importance. But the stratigraphic scopes and boundaries of some members M and F do not coincide, e.g., in the Mys Ploskii Formation and the lower part of the Yunyun'vayam Formation. In this case, six members M (III to VIII) correspond to three members F (III to V). With only M members III to V being approximately correlative with F members III to the base of IVF. Thus, the Neogene of Karaginskii Island is subdivided into 10 - 15 members, which are well identified and can be correlated with these from other regions. Given in a previous monograph (Gladenkov *et al.*, 1992), a detailed description of these members is omitted herein. Characteristics of the Ust'-Limimtevayam Formation (Pliocene) is given here to demonstrate the recognition of these members in practice (Fig. 2).

Member XIVM includes *Astarte diversa–A. nortonensis*. The assemblage consists of 36 species. Thirteen species, including *Astarte* and *Cyrtodaria*, appear for the first time. *Astarte, Macoma, Chlamys karaginskiensis, Serripes groenlandicus*, and *Mya truncata* are dominant. Six fossil forms, 31 species living now and

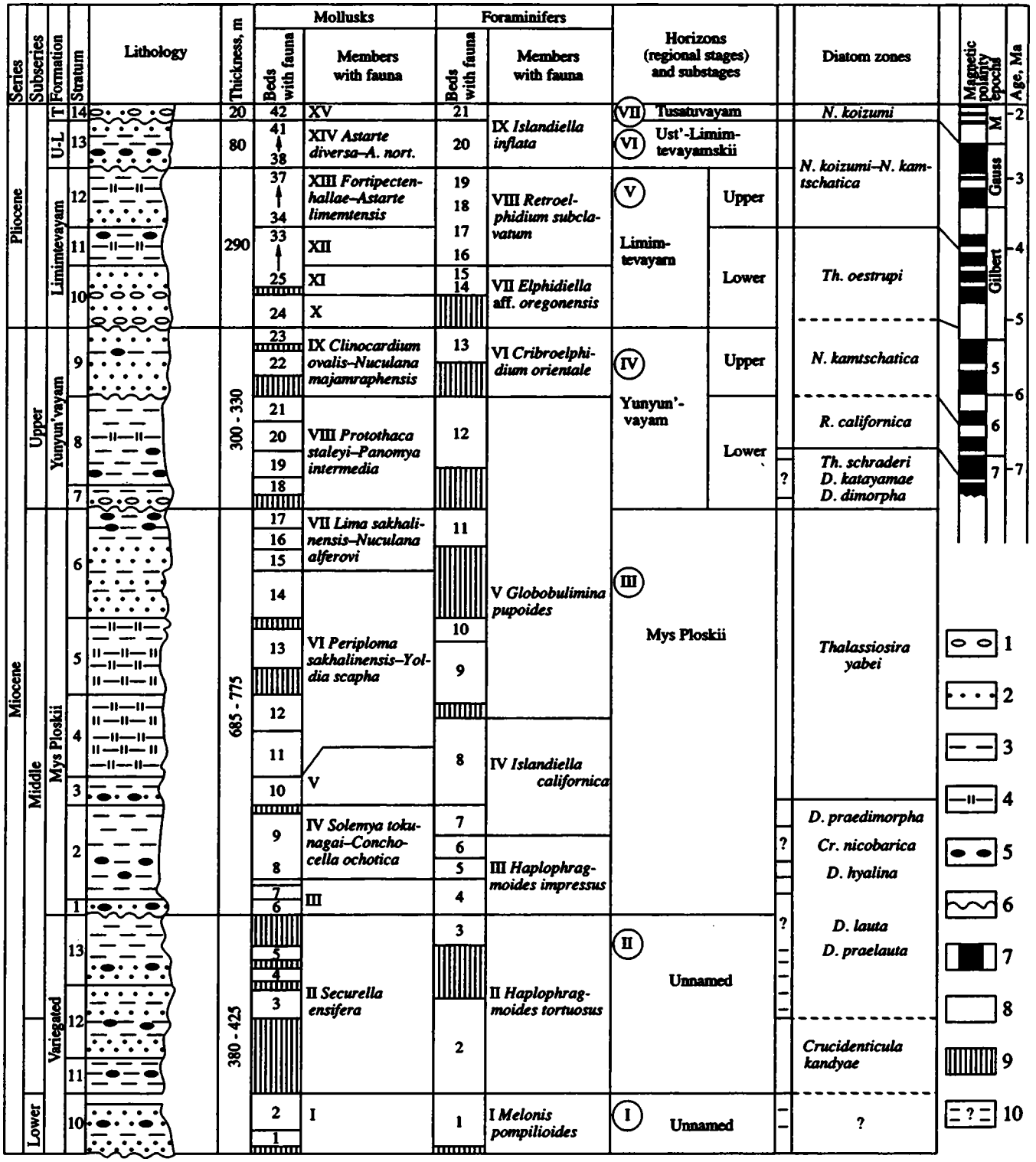

Fig. 1. Horizons, zones, beds and members with fauna of the Neogene of Karaginskii Island.

1 – Conglomerates; 2 – sandstones; 3 – siltstones and claystones; 4 – diatomites; 5 – concretions; 6 – hiatuses and erosion; 7 - 8 – magnetic polarity: 7 – normal and 8 – reversed; 9 – interbeds; 10 – without zonal assemblages. U-L – the Ust'-Limimtevayam strata; T – the Tusatuvayam Beds; M – Matuyama. I - XV – Members with mollusks: I – *Hiatella pleshacovi–Pseudoliomesus praenassula*, III – *Mya karaginskiensis*, V – *Shavodrilla kamtshatica–Turcicula asawanoensis maxima*, X – *Panomyatrapezoidis–Yoldia ochotensis*, XI – *Fortipecten kenyoshiensis*, XII – *Fulgoraria microsculptata–Plicifusus karaginskiensis*, and XV – *Mytilus declivis–Clinocardium subcostalis*. N – *Neodenticula*, R – *Rouxia*, and D – *Denticulopsis*.

Formation	Stratum	Mollusks: Members with fauna	Mollusks: Members with fauna	Foraminifers: Beds with fauna	Foraminifers: Members with fauna	Horizons: Percentage of living mollusks
	14	42. with *Mytlius edulis declivis*	XV. *Mytlius edulis declivis–Clinocardium subcostalis*	21. *Hyanesina orbicularis–Buccella conica*	IX. *Islandiella inflata*	Tusatuvayamskii (93%)
Ust'-Limimtevayam	13	41. with *Mya truncata* 40. with *Nuculana pernula–Yoldia amugdalea hyperborea* Interbed 39. with *Chlamys karaginskiensis–Cyclocardia pliocenica* 38. with *Astarte nortonensis–Cyrtodaria kurriana*	XIV. with *Astarte diversa–A. nortonensis*	20. *Islandiella inflata–Buccella pseudofrigida*		Ust'-Limimtevayamskii (85%)
Limimtevayam	12	37. with *Macoma brota–Mya* cf. *pseudoarenaria* 36. with *Acila marujamensis–Macoma brota* 35. with *Serripes groenlandicus–Cyclocardia veniaminovi* 34. with *Fortipecten hallae–Astarte limimtensis*	XIII. with *Fortipecten hallae–Astarte limimtensis*	19. *Retroelphidium hughesi–Epistominella*	VIII. *Retroelphidium subclavatum*	Limimtevayamskii (62 - 70%)
	11	33. with *Conchocelle disjuncta–Leionucula tenuis expansa* 32. with *Macoma brota–Plicifusus karaginskiensis* 31. with *Callithaca adomsi–Fulgoraria microsculptata* 30. with *Macoma brota–Mya cuneiformis* 29. with *Nuculana pernula–Acila marujamensis*	XII. with *Fulgoraria microsculptata–Plicifusus karaginskiensis*	18. *Islandiella yaponica–Bolivina* cf. *pseudopunctata* 17. *Islandiella cushmani–Nonionella globosa* 16. *Cribroelphidium vulgare–Islandiella laticamerata*		
	10	28. with *Fortipecten kenyoshiensis* 27. with *Macoma enemtensis–Cyclocardia crebricostata* 26. with *Fortipecten kenyoshiensis*	XI. with *Fortipecten kenyoshiensis–Macoma enemtensis*	15. *Elphidiella arctica–Cibicides rotundatus* 14. *Elphidiella nagaoi–Elphidiella* aff. *oregonensis*	VII. *Elphidiella* aff. *oregonensis*	
		24. with *Panomya trapezoidis–Yoldia ochotentis* Interbed	X. with *Panomya trapezoidis–Yoldia ochotensis*	Interbed		

Fig. 2. Horizons, members and beds with fauna of the Pliocene of Karaginskii Island.

3 characteristic species (*Astarte nortonensis*, *A. hemicymata*, and *A. diversa*), are known from the Pliocene sediments of the Beringia transgression in Alaska. 3 endemics occur there as well. The recent species include 9 widespread boreal, 17 boreal-arctic, and 5 high boreal ones.

Member IXF with *Islandiella inflata*. The assemblage contains 20 species: 7 new, 4 transitional, and 9 eliminated. The characteristic species are *Fissurina lucida* and *Islandiella kaziwazakiensis*. *Bucella pseudofrigida* predominate. The appearance of new species *Bucella conica*, *B. sachalinica*, *Islandiella inflata*, and *I. kaziwazakiensis* is characteristic. In addition to the boreal-arctic forms, the boreal species, which are now missing in the high latitudes, occur there in abundance. The member yielded many species identical to the Pliocene forms of the Pomyr Horizon in Sakhalin.

Probably, it is these units that should be ranked as "beds with geographic names." Some of them have been already named, e.g., the Ust'-Limimtevayam Beds and the Tusatuvayam Beds.

Some of these members (beds) with fauna can be considered as local or regional zones.

No complete Neogene sections are found in east Kamchatka as it is in the Karaginskii Island. Fragments of the sections occurring there were studied at the formation level, not as a bed. This makes tracing these members (zones) over the region difficult, although some of them are recorded in the Valaginskii Range, the Kumroch Range, and other places of east Kamchatka. Some members appear to be analogous to those from adjacent regions of Kamchatka and Sakhalin, where faunal and floral remains were studied from every bed. Thus, member IIM with *Securella ensifera* from the base of Middle Miocene is distinctive in the Neogene sections in the Korf region (northeast Kamchatka), the Tigil' and Kavran regions (west Kamchatka) as well as in south Sakhalin and even northern Japan. Many regions show a local zone of *Lima sakhalinensis–Nuculana alferovi* (M) from the upper part of the Middle Miocene. The Pliocene local zones of *Elphidiella oregonensis* (F), *Retroelphidium subclavatum* (F), and *Fortipecten kenyoshiensis* (M) can also be clearly traced. Some Pliocene members (or local zones) – *Fortipecten hallae–Astarte limimtensis* (M) and *Astarte diversa–A. nortonensis* (M) – are found in Alaska.

A number of such local zones will increase, but the reclassification of members and beds into local zones requires a thorough analysis of the stability of zonal assemblages throughout the basins and the similarity of their successions and stratigraphic positions in the sections. After revision some of them may remain local beds. Much work is needed to calibrate these units. The important hierarchic and stratigraphic status of the members under discussion should be stressed regardless of the category, beds or local zones, they refer to. Their integration forms the basis for recognizing horizons (or regional stages), i.e., the most significant regional units corresponding to certain stages within the geological development of a region, which (stages) are reflected in biotic evolution (particularly of the benthic groups) and sedimentary peculiarities.

HORIZONS AND ZONES

The Neogene section of the discussed region shows six horizons (from below upward): the Lower Miocene–the base of the Middle Miocene: two unnamed horizons corresponding to the Variegated Formation; the Middle Miocene: the Mys Ploskii Horizon; the Upper Miocene: the Yunyun'vayam Horizon; the Pliocene: the Limimtevayam, Ust'-Limimtevayam, and Tusatuvayam horizons. It is very important that this section includes sediments that are less distinctive or missing in the reference Neogene section of west Kamchatka. So, the Upper Miocene Erman Horizon of west Kamchatka is represented principally by continental facies, and marine beds are recorded in its lowermost part only. The Enemten Horizon corresponds to the lower part of the Pliocene, whereas the Upper Pliocene is absent in west Kamchatka. In other words, the horizons, recognized in the stratotype section of west Kamchatka in the 1950s and used widely as the standard units for Kamchatka, were complemented with new horizons (regional stages of the marine Upper Miocene and Upper Pliocene from Karaginskii Island). The new horizons fill in gaps in the Neogene scheme of Kamchatka, helping to develop the stratigraphic scheme of the area on the basis of regional stages.

The Neogene horizons of formation rank were eventually recognized in Karaginskii Island as early as the late 1960s - 1970s (Gladenkov, 1972). Modifications of the regional scheme presented here are a subdivision of the Variegated Formation into two horizons (I and II) and the recognition of the Tusatuvayam beds as a separate horizon of the Upper Pliocene (VII).

As mentioned above, in addition to the benthic groups, the planktonic forms, particularly diatoms, were used to subdivide the Neogene of Karaginskii Island. The recognition of six diatom zones allowed us to correlate some strata (the Miocene strata 11, 12 of the Variegated Formation, 3 - 8 of the overlying formations, the Pliocene strata 11 - 13, and the Tusatuvayam beds) to the Standard Scale. But the lack of diatoms in strata 10 and 13 of the Variegated Formation and in strata 1, 2, 9, and 10 of the overlying formations indicates that some zones are separated by a gap. Although these zonal units are absent, the regional stages can be reliably dated. The Early Miocene *C. kanayae* Zone is distinguished in regional stage II, the Middle Miocene *T. yabei* Zone in the Mys Ploskii Horizon (III), the Late Miocene *R. californica* Zone in the Yunyun'vayam Formation (IV), and the typical Pliocene zones in the three uppermost horizons (V to VII). The scopes of the zones appear to be less than those of the horizons (for account of interzones), though they are equal in general. The exception is the Ust'-Limimtevayam Horizon (VI), which became a part of the *N. koizumi–N. kamtschatica* Zone. The relationship between zones and other units

suggests that zones (based on diatoms) are usually larger units than members and beds with fauna (2 - 2.5 and 3.5 - 7 times, respectively).

Thus, the following hierarchy of stratigraphic units was used to subdivide the Neogene of Karaginskii Island: bed with fauna – monotaxon and polytaxa members (beds) with fauna corresponding in rank to beds with geographical names (or local zones)–zones–horizons (regional stages).

But this system of units, which was formed empirically for a particular section of east Kamchatka, can be modified in geological practice. For example, if zones are not distinctive in the shelf sections, members with fauna can be united into regional stages. This is a common practice, as the units related to the parasubdivision form a natural chain from finer local and regional divisions to larger ones (beds–members–horizons), whereas zones based on the orthogroups appear to be (especially in the case of unjoined zones) the complementary units included in the regional scheme as if parallel to the others.

Such a situation is infrequent, however it is typical of the transitional regions from ocean to continent (sections of shelf, marginal, and inner basins, and so on). Nevertheless, stratigraphers should not be confused: the only proper way to develop a system of stratigraphical units for a region is the utilization of all biotic groups in spite of apparent and real formal difficulties. The current practice shows that regional stages (horizons) integrate most fully and reliably the units of para- and orthosubdivision. So, they belong to stratigraphic units of combined substantiation (taking into account lithological and magnetic characteristics of the strata). Some finer subdivisions – many zones and beds with geographical names (or members with fauna) – can be referred to such units as well, in the case where they are characterized by various fossil groups and other (e.g., physical) properties.

Dating the above units, such as horizons (and members constituting them) and finer units (beds with fauna), is a special problem.

As mentioned above, horizons are dated using assemblages of diatoms and benthic groups (mollusks and foraminifers). Horizon I was assigned to the Lower Miocene by these two benthic groups (M and F). Some discrepancy exists among age estimates for horizon II: diatoms (D) indicate an Early Miocene age for its uppermost parts, but mollusks (M) and foraminifers (F) suggest a Middle Miocene age. So, the Lower-Middle Miocene boundary is tentative. The Mys Ploskii Horizon (III) was assigned to the Middle Miocene by means of diatoms (D) and mollusks (M), and to the Middle-Upper(?) Miocene by foraminifera (F). The Yunyun'-vayam Horizon (IV) was referred with all these groups (D, M, and F) to the Late Miocene. Finally, the age of the three uppermost horizons (Limimtevayam, Ust'-Limimtevayam, and Tusatuvayam) (V - VII) was estimated as the Pliocene. The Lower Pliocene boundary is drawn at the base of strata 10, and the upper one at the top of the Tusatuvayam beds, which correspond to the uppermost zone of the Pliocene.

Consistent data on D, M, and F reliably correlate the Karaginskii strata with horizons and formations of adjacent regions (Kamchatka, Sakhalin, northern Japan, from one side, and North America, from the other side).

The age estimates for the formations made in 1979 (Gladenkov *et al.*, 1982) are not changed in this variant of the stratigraphical scheme, however all the dates were analyzed and were well substantiated. The Pliocene age of the Tusatuvayam beds is a new date. Earlier they were referred to the Quaternary. Both the Lower and Middle Miocene beds were recognized in the Variegated Formation, but this is disputable as paleontologic data is inconsistent.

PHYSICAL METHODS FOR THE DETERMINATION OF THE AGES OF THE STRATIGRAPHIC UNITS

Physical methods supply very important data for the determination of the ages of the formations and strata. In some cases, they control biostratigraphic dating, in other cases, their help is provisional.

The K-Ar dating of the base of stratum 9 of the Yunyun'vayam Formation in the Karaginskii section is 9.4 ± 0.9 Ma (determination of M.L. Zilberman, USA) (Gladenkov and Shantser, 1978). This date is consistent with the paleontologic evidence that suggests a Late Miocene age. However, applying the diatom-based scale reveals some discrepances. Boundaries of the *Rouxia californica* Zone related to strata 7 and 8 of this formation are dated 7.3 and 6.6 Ma, but the overlying stratum 9 appears to be older – more than 9 Ma. The ages obtained through fission-track for stratum 8 range from 6.95 ± 0.58 to 6.22 ± 0.57 Ma, i.e., they also show certain discrepancies. So, the accuracy of the K-Ar dating is questionable.

In addition to faunal and floral remains, paleomagnetic records were used to date the Upper Miocene and Pliocene sediments. The section shows the Matuyama, Gauss, and Gilbert orthozones; a seventh paleomagnetic zone was provisionally distinguished there. Certain age limitations (in Ma) within the Standard Scale permit them to be compared with the results obtained through fission-track dating. This method produced 11 ages for the Upper Miocene and Pliocene ash tuffs (7 ages for the Pliocene strata). The ages reflect the stratigraphic position of the samples; no inconsistent cases have been recorded. Nevertheless, a comparison between the diatom and paleomagnetic zonations shows that the track ages for some beds are generally younger. Although the discrepancy is estimated to be 0.5 - 1.0 Ma, special discussion is required to develop detailed scales. Apparently, on the one hand, the paleomagnetic interpretations should be improved and, on the other hand, there may be defects in the fission-track dating. Applying physical methods to determine the ages of ancient sediments is thought to be very useful in spite

of the discrepancies in results obtained by different methods. These methods produce reliable ages for larger units – formations and strata. This seems to be of the utmost importance.

ESTIMATION OF THE TIME RANGE OF FINER STRATIGRAPHIC UNITS

Ages of finer units and separate levels should be specified more carefully. Certain limitations of radiometric and fission-track methods and ambiguities concerning paleomagnetic interpretations of a section require a thorough consideration of age values, i.e., without becoming overly concerned on them and admitting the possibility of various interpretations (since the percentage of errors in measurements by every method is usually indicated). The stratigraphic subdivision of sections is principally based on paleontological evidence. Such subdivision provides both the reconstruction of the real stratigraphic succession of strata and the definition, to some extent, of their age ranges.

The task was to estimate the duration of finer stratigraphic units recognized in the section under discussion in order to compare them with the Quaternary units.

The determination of the ages of the beds and members was based on the dating of boundaries of the diatom zones and paleomagnetic orthozones (and events) and on the estimation of time intervals according to the sedimentation rate (about 2.5 cm/1000 years) made by A.E. Basilyan. The age ranges of the 7 uppermost strata of the Neogene (the Upper Miocene to Pliocene) in the Karaginskii section were defined as follows. Stratum IX (from the base to the top) represents about 1 Ma. The age of stratum X is about 0.12 Ma (hence, each of the two constituent beds with mollusks accumulated over a period of 0.06 Ma). The age range of stratum XI is estimated to be 0.16 Ma (each of the three beds is about 0.05 Ma). Stratum XII is 0.15 Ma in duration (each of the five beds corresponds to the interval of 0.03 Ma). The age range of stratum XIII is nearly 0.25 Ma (each of the four beds is 0.06 Ma long). As for stratum XIV, the values are as follows: 0.35 Ma for the entire stratum and 0.09 Ma for each of the four beds. The deposition period of stratum XV is estimated to be 0.05 Ma.

The above data shows an extraordinary refinement of the Pliocene divisions: the duration of members with fauna is estimated to be 0.12 - 0.35 and that of beds to be 0.03 - 0.09 Ma! This means that the detailed subdivision of the Pliocene is comparable with that of the Quaternary. This is the first time that a subdivision based on a reliable age estimation for each fine unit has been established for Kamchatka and Sakhalin.

Future computer processing of datum planes of different types (levels of appearance and disappearance of taxa) may produce even higher stratigraphical resolution. At present, every formation shows additional levels of varying reliability and the subdivision of some beds into subbeds cannot be excluded. A number of markers indicating the appearance or "extinction" of certain foraminiferal and molluskan species can be distinguished in almost every formation. This increases the total number of markers within the Neogene sediments of the section. So, the Variegated Formation exhibits 5 to 6 foraminiferal levels and 1 to 2 molluskan levels, in addition to the boundaries of the beds and members. The Mys Ploskii and Yunyun'vayam formations each show 3 levels by foraminifers and 3 levels by mollusks. There are 3 additional levels by foraminifers and 4 level by mollusks in the Limimtevayam Formation. Thus, an analysis of datum-planes and bed limits can provide a further refinement of the Neogene units. Using quantitative methods to make stratigraphic schemes more detailed may be a promising line for future investigations.

Such analysis is common when oceanic sediments are studied. Nearly 175 levels of appearing and disappearing planktonic forms were distinguished in the Miocene of some oceanic sections, including Pacific ones. More than 70 levels were correlated to the paleomagnetic scale (Barron *et al.*, 1985). In this case, resolution appears very high. However, correlation of the finer units recognized by means of planktonic and benthic forms as well as their steadiness throughout the entire provinces requires long-term studies.

CONCLUSION

The recognition of finer stratigraphic units in the Neogene of Kamchatka can be used to develop more detailed stratigraphic schemes of the Cenozoic in Sakhalin and other adjacent regions, such as Japan, Alaska, and others. Elaborating such schemes throughout the North Pacific, including the ocean and its margins, will form the basis for reconstructing paleogeographic events and defining a trend of future environmental changes. A recent study of the history of the Pra-Bering Strait (Gladenkov *et al.*, 1992) serves as an example of the reconstruction of the North Pacific biotic and abiotic phenomena. This study allowed us to define eustatic fluctuations of a global ocean level, which produced four sedimentary cycles: to determine the peaks of the marine transgressions (about 5, 4, 3 and 2.2 Ma); to estimate the duration (0.2 - 0.6 Ma) of hiatuses, which coincide with terrestrial fauna migrations via the Bering Bridge; to date the opening of the Pra-Bering Strait (about 4 Ma ago), which resulted in an exchange of the Arctic and Pacific marine biotas; and to reveal some periods of volcanic activity and coolings.

Developing a procedure for the detailed subdivision of strata, and the experience gained while developing this procedure, may facilitate the confirmation of microstratigraphic units and the elaboration of detailed correlation schemes. These units will form a basis for the reconstruction of both extended and brief successive geological events. It may also correct many notions concerning the character of past changes in the lithosphere, biosphere and hydrosphere.

Notions concerning global trends in the development of our planet can be revised and prognoses of

future environments can be made on this basis only. These investigations should form a large self-contained project.

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Magnetostratigraphic Scheme of the Cenozoic in Mongolia

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Abstract – For the first time paleomagnetic data is presented for Mongolian Cenozoic stratotypes and reference sections that are characterized by mammal fauna assemblages. Potassium-argon (K-Ar) and thermoluminescence (TL) ages are defined for a number of stratigraphic horizons. The magnetostratigraphic scale of the Cenozoic in Mongolia is correlated with the scale of Harland *et al.* (1982), and a direction of further magnetostratigraphic studies is indicated.

The paleomagnetic method is currently gaining importance not only in regional stratigraphy, but also in the correlation and geochronologic age estimation of stratigraphic units. The advantage of this method is its applicability to heteromesic marine and continental sediments, and to effusive formations that may be radiometrically dated. In particular this method is widely and successfully used, both in this country and abroad, for Late Neogene and Anthropogene within the framework of Cox's scale (*Geokhronologia ...*, 1974; Cox and Doell *et al.*, 1965; Menner *et al.*, 1972; Pevzner, 1972; Pevzner *et al*, 1982; Khramov, 1958; Cox, 1969). Local magnetostratigraphic scales of the Late Pliocene and Anthropogene were created for a number of regions, among them, the Dniester region, southern Ukraine, Transcaucasus, Tadjik depression, southern West Siberia, Altai, Kamtchatka, and others. Magnetostratigraphic data on the lower levels of the Cenozoic was obtained in a limited number of places, both in Russia and beyond. General magnetostratigraphic scales of the Mesozoic and Cenozoic have also been suggested (Berggren, 1972, Berggren *et al.*, 1974; Harland *et al.*, 1982; Lowrie and Avarez, 1981).

The application of the paleomagnetic method in studies of continental deposits is a more complex problem. This is principally caused by the incompleteness of stratigraphic sequences with more frequent hiatuses as compared to marine sections, and by more rare occurrences of fauna impeding detailed biostratigraphic subdivision.

In the territory of Mongolia, the paleomagnetic method was previously used in studies of the Pliocene, Pleistocene, Eopleistocene, and, to a lesser extent, Quaternary sediments and effusive formations (Badamgarav *et al.*, 1973; Devyatkin, 1981; Korina, 1974; Korina *et al.*, 1973; Pevzner *et al.*, 1982).

E.V. Devyatkin, I.G. Liskun, and D. Badamgarav used the paleomagnetic method in studies of reference sections of the Upper Cretaceous, Paleocene, Neogene, and Pleistocene. Particular attention was paid to the paleomagnetic investigation of sections with the most complete paleontological data and to effusive formations that have been radiometrically dated. The Quaternary sedimentary sections dated by thermoluminescence method (TL) were also studied.

The main goals of the present paper are as follows: (a) to define paleomagnetic characteristics of Cenozoic deposits that contain well known biostratigraphic complexes of mammalian fauna; (b) to characterize by paleomagnetic data the effusive rocks dated by the K-Ar method; and (c) to obtain the paleomagnetic data characterizing sedimentary horizons of Eopleistocene and Pleistocene dated by TL method. As a whole, these define the main objective; the creation of a general magneto-biostratigraphic and geochronologic scale of the continental Cenozoic deposits in Mongolia as a reference region of the Inner Asia.

The laboratory paleomagnetic measurements of sedimentary and effusive rock samples was carried out by M.A. Pevzner and I.G. Liskun at the Geological institute of the Russian Academy of Sciences using well-known methods. The samples from Paleocene and Neogene sections of Mongolia number about one thousand. The sampling interval was defined according to the nature of sediments, and varied from 0.25 to 10 m. Repeated sampling along the strike was used in case of basaltic horizons or flows. TL dating was conducted by V.N. Shelkoplyas (Institute of Geological Sciences, Ukrainian Academy of Sciences).

The results of the magnetostratigraphic study of the composite sequence of the Paleogene, Neogene, and partly Pleistocene in Mongolia are presented in Fig. 1. Figure 2 shows the localities of Cenozoic reference sections in Mongolia.

We consider the composite paleomagnetic section of the Upper Cretaceous and Cenozoic in Mongolia the first experimental version. Its resolution clearly needs further improvement, especially in the characterization of unsampled parts of the scale. Though provisional, the present study is significant, as it was the first attempt to obtain paleomagnetic data for a number of biostratigraphic horizons. In the future, it will be possi-

ble to apply the paleomagnetic method to stratigraphic correlations in other parts of Inner Asia. The paleomagnetic data obtained for sedimentary and effusive rocks dated using the K-Ar method, and for the Pleistocene deposits dated using the TL technique are definitely important for this. Below, the results of the magnetostratigraphic studies of the Upper Cretaceous, Paleogene, Neogene, and Pleistocene sequences in Mongolia are briefly discussed.

The Upper Cretaceous: (a) The Burungoiot Formation (the Campanian). The paleomagnetic method was used to study the upper 80 m of the Bain Dzag section. The section contains well-known Dzhadokhta fauna with remains of dinosaurs and primitive multituberculate mammals (Berkey and Morris, 1927; Leafed, 1971; Kielan-Jaworowska, 1970). The section consists of orange and red fine-grained sands and unconsolidated sandstones of coastal lacustrine genesis. Eolian material was also registered there (Kaie and Devyatkin, 1969). Sediments in the section have, on the whole, stable reversed (R) magnetization, with the exception of a thin (5 m) layer of normally (N) magnetized rocks.

(b) Nemeget Formation (the Maestrichtian). The uppermost part (20 m) consists of red sandstones and clays of fluviolacustrine genesis. These deposits contain fauna of dinosaurs, mollusks, ostracods, and charophyts (Barsbold, 1972). Rocks of the Naran Bulak and Khaichin-1 sections have a stable N-magnetization.

(c) Dzun Mod Formation (the Maestrichtian is apparently its uppermost part). Paleomagnetism was studied in the Khaichin-1 section. The formation overlies Nemeget deposits with a minor erosional unconformity. Deposits are represented by 20 - 25 m thick light gray sandstones of fluviolacustrine genesis. They contain mammalian fauna of *Buginbaatar transaltanensis*. Previously, these deposits were considered to be of the Lower Paleocene. At present, the Nemeget-type ostracods and mollusks as well as dinosaurs indicate that the formation formed during the Late Cretaceous. Paleomagnetic studies of this section demonstrated the normal polarity of the rocks, as is the case in the upper parts of the Nemeget Formation.

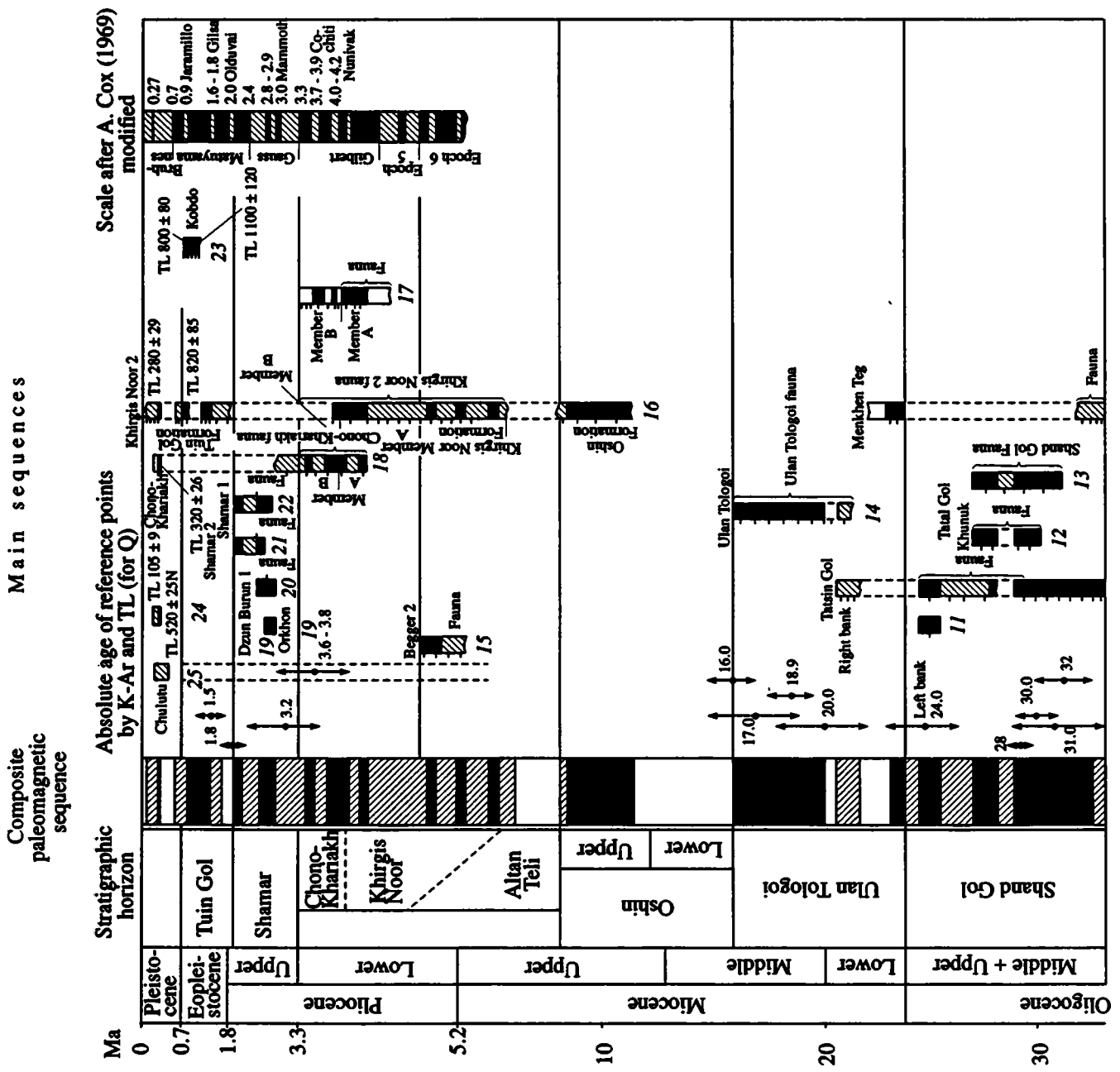
The Upper Paleocene. Naran Bulak and Khashat formations (the Gashato Horizon). Deposits of this age bear a mammalian assemblage of *Prionessus*, *Hyreolestes*, *Sarcodon*, *Eurymylus*, *Dissacus*, and *Paleostylops*. The horizon is older than 56 Ma (Devyatkin, 1981). The most detailed paleomagnetic studies were performed in two sections of Khashat and Naran Bulak. The sections Khaichin 1 and 2 turned out unfavorably, as their rocks contained weak magnetic properties. In the Khashat section, the lower part of the clayey red member has a N-magnetization, and the upper part is R-magnetized. Mammalian fauna (Gashato locality) is known from both magnetostratigraphic horizons. In the Naran Bulak section, the lower part of the formation (red proluvial member) has a stable R-magnetization, the middle member of the fluviatile white sands has weak magnetic properties (as well as in the upper part of the Khaichin 1 section), and the upper lacustrine red member is N-magnetized. Possible paleomagnetic correlations within the Gashato Horizon are illustrated in Fig. 1.

The radiometric age of the Gashato Horizon is controlled by a several K-Ar datings. The oldest age, 56 ± 3 Ma, (Toru Aigyr) was measured in basalts from the Issyk-Kul' Depression. These basalts directly underlie deposits with fauna of the Khaichin Horizon (Middle and Upper Eocene). Ages of 51 ± 2 Ma (Khashat) and 53 ± 8 Ma are clearly younger than the upper time limit of the Gashato Horizon. The latter dated from basalts that overlie the Paleocene deposits near Mt. Khuts Ula in the Khurmen Somon (Nikolaeva and Shuvalov, 1979). In the same region, basalts underlying the Paleocene deposits are defined to be as old as 61 ± 8 Ma.

Eocene. The uppermost part of the Naran Bulak section (Argut member), which contains fauna of *Comphos elcema* of the Early Eocene (Dashzeveg, 1981) has not been characterized by paleomagnetic data. In the Khashat region, a basaltic flow with a K-Ar age of 51 ± 2 Ma and enclosing sediments 10 m thick have a normal polarity. These basalts correspond to the middle part of the composite Khashat sequence with *Comphos elcema* mammalian fauna of the Early Eocene (Zhegallo and Shevyreva, 1976). In the same region (Barun Tabun Khairkhan Ula Mt.), basalts overlying the Upper Cretaceous sediments have a K-Ar age of 47 ± 2 Ma and N-magnetization (Devyatkin, 1981).

The Middle and Upper Eocene (Khaichin Horizon) is studied by the paleomagnetic method in five sections: Khaichin 3 and 5 (Khaichin Formation) in Transaltai Gobi; Barun Khutsyn Tsav, Tsagan Khutel, and the lower part of Menkhen Teg section (Kolobolchi Noor Formation) in the Lakes Valley. Both formations consist of sands, silts, and clays of predominantly lacustrine and, to a lesser extent, fluviolacustrine origin. The Khaichin Horizon is characterized by the fauna assemblage of *Teleolophus–Deperetella–Lophialetes*. In general, these formations correspond to the Irdyn Manga and Shara Muren formations of China. The radiological age of the Khaichin Horizon is estimated to be from 51 to 42 Ma (Devyatkin, 1981). Paleomagnetic studies have shown a stable N-magnetization for the Khaichin 3 and 5 sections. A zone of R-magnetized rocks was found in the Menkhen Teg, Barun Khutsyn Tsav, and Tsagan Khutel sections. This zone grades upwards into a zone of N-magnetized rocks bearing a narrow episode of reversed polarity in a more complete sequence of Menkhen Teg.

Lower Oligocene. Sections of this age have been studied in the stratotype of the Ergelyeen Dzo Formation (the Ergelyeen Dzo section), Menkhen Teg section, and in sections from the right bank of the Tatsin Gol River. Deposits include light, sometimes carbonate sands, and clays with interlayers of red clays, and lenses of gravel and pebbles. They were formed under lacustrine and fluviatile conditions, and contain the *Brontho-therium* type fauna with a specific association of *Protembolotheriucm–Embolotherium–Parabrontops*.


Composite paleomagnetic sequence
Main sequences
Absolute age of reference points by K-Ar and TL ((for Q)
Scale after A. Cox (1969) modified
Stratigraphic horizon
Ma
Pleisto-cene
Eoplei-stocene
Pliocene
Miocene
Oligocene
Upper
Lower
Middle
Tuin Gol
Shamar
Chono-Kharlakh
Khirgis Noor
Altan Teli
Oshin
Ulan Tologoi
Shand Gol
Chulutu
Dzun Burun 1
Orkhon
Shamar 1
Shamar 2
Khirgis Noor 2
Begger 2
Tatal Gol
Khunuk
Tatsin Gol
Right bank
Left bank
Menkhen Teg
Fauna
Formation
Member
Epoch 5
Epoch 6
Gilbert
Gauss
Matuyama rev.
Brunhes
Kobdo
Jaramillo
Olduvai
Mammoth
Nunivak

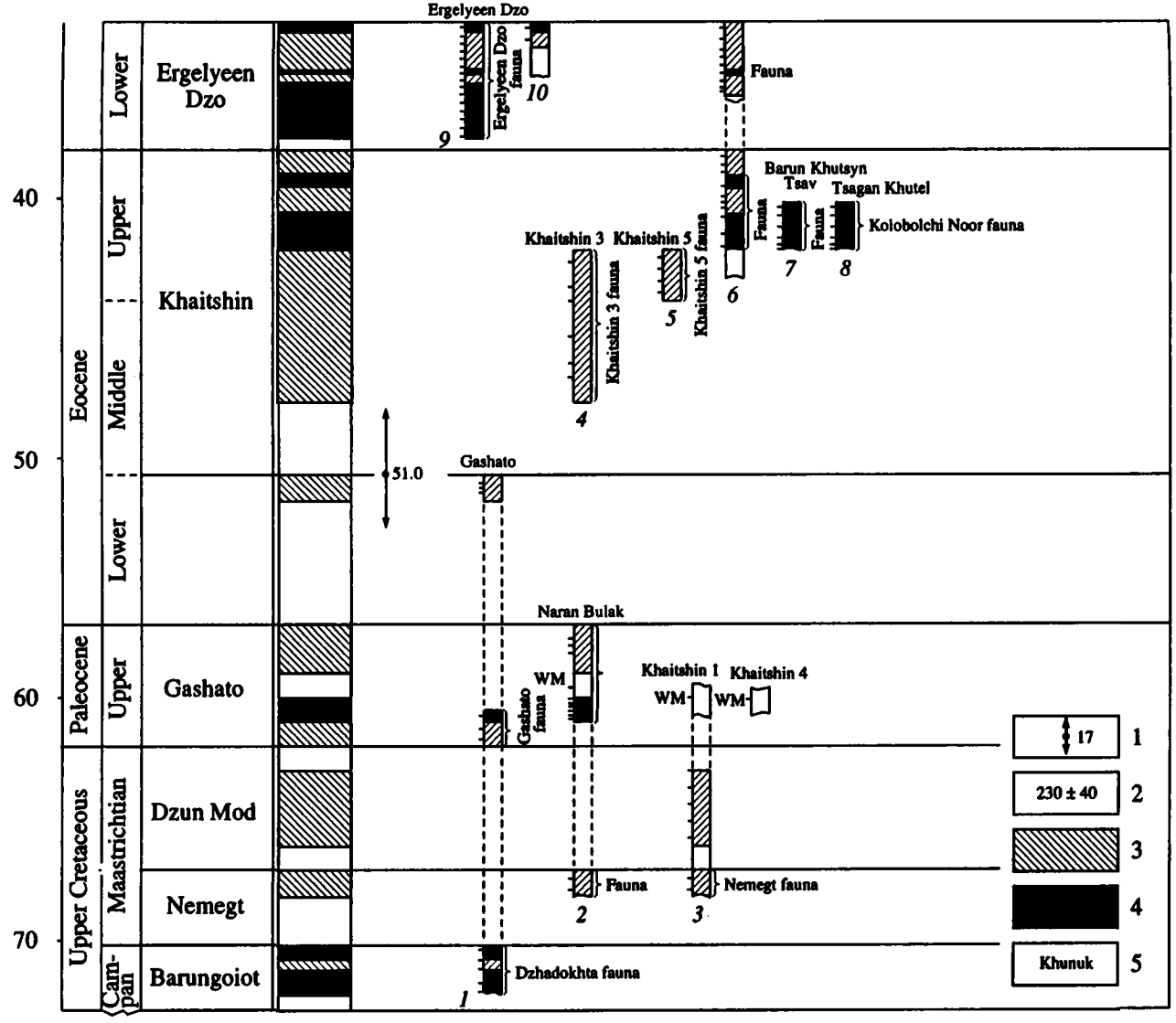


Fig. 1. Paleomagnetic and radiometric data for main Cenozoic sections in Mongolia.

1 – Radiometric ages (Ma), K-Ar method; 2 – radiometric ages (ka), TL method; 3 – normal polarity (N); 4 – reversed polarity (R); 5 – reference sections and mammalian fauna localities. WM is the weak magnetization. Number under sections correspond to those in Fig. 2.

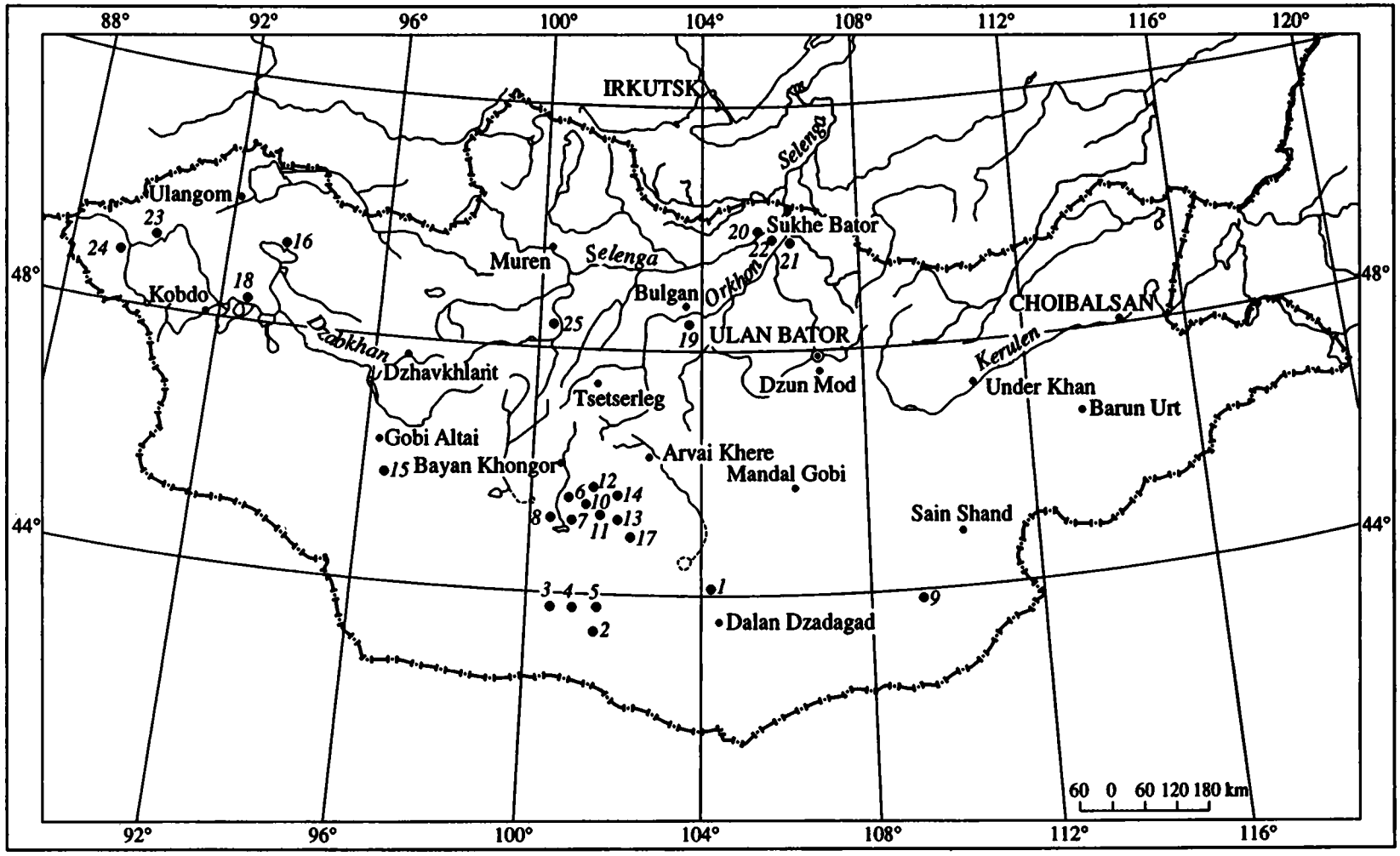


Fig. 2. Reference paleomagnetic sections of Mongolian Cenozoic (dot numbers match section numbers on Fig. 1).

Reference sections: *1* – Gashato; *2* – Naran Bulak; *3* – Khaitshin 1 and 2, Khaitshin 3, Khaitshin 5; *6* – Menkhen Teg; *7* – Barun Khutsyn Tsav; *8* – Tsagan Khutel; *9* – Ergelyeen Dzo; *10* – Tatsin Gol (right bank); *11* – Tatsin Gol (left bank); *12* – Khunuk; *13* – Tatal Gol; *14* – Ulan Tologoi; *15* – Begger 2; *16* – Khirgis Noor 2; *17* – Khung Khure; *18* – Chono-Khariakh; *19* – Orkhon; *20* – Dzun Burin; *21* – Shamar 2; *22* – Shamar 1; *23* – Kobdo; *24* – Ulan Khus; *25* – Chulutu.

In the stratotype, the lower part of the Ergelyeen Dzo Formation, the red clayey and light lacustrine members are R-magnetized. The upper part of the formation is mainly N-magnetized, but has two narrow zones of reversed polarity. In the Menkhen Teg section, only the upper part of the formation was studied. The narrow zone of reversed polarity that was registered here within the N-magnetized rocks may correspond to the lower reversed zone in the upper part of the stratotype. On the right bank of the Tatsin Gol River, a presence of R-magnetized rocks was established below the lower boundary of the overlying Middle-Upper Oligocene Shand Gol Formation. However, in the Menkhen Teg sequence, the boundary between the two formations lies within a zone of normal polarity. The age of the Ergelyeen Dzo Horizon is estimated to be 37 - 32 Ma (Devyatkin, 1981).

The Middle and Upper Oligocene is represented by the Shand Gol Formation, which is estimated to be as old as 32 - 24 Ma (Devyatkin, 1981; Devyatkin and Smelov, 1979). Sediments of this horizon are represented by red clays and sandstones predominantly proluvial in origin. They contain mammalian fauna of *Indricotherium* and *Tsaganomys*. Paleomagnetic studies were conducted in five sections, namely, along the Tatsin Gol (both banks), Khunug, Tatal Gol rivers, and in the upper part of Menkhen Teg section. Over a large area of Mongolia, the lower part of the Shand Gol Formation has a stable R-magnetization with a narrow zone of normal polarity at the very base of the formation (the Menkhen Teg section). The lower basaltic layer in the Shand Gol, Tatal Gol, Dzabkhan sections, which have a K-Ar age of 28 - 32 Ma, also has a stable reversed magnetization. Rocks of the upper part of the Shand Gol Horizon vary in their magnetization, having two R and three N zones. The upper basaltic layer, which has a K-Ar date of 24 - 25 Ma, is R-magnetized in the section on the left bank of Tatsin Gol River.

Miocene. The sediments of this age are poorly studied so far. Extensive gaps in sampling hamper efforts to obtain their complete paleomagnetic characteristics. In the lower part of the Ulan Tologoi Horizon, which bears *Mastodon* and *Anchitherium* fauna of the Lower-Middle Miocene, an alternation of two or more zones with different polarities is recognized in three sections. In the stratotype section of Ulan Tologoi, the upper part of the horizon has a stable R-magnetization. Basaltic flows at the base of the Loh Formation, (20 ± 0.5 Ma) as well as overlying basalts (18 - 16 Ma), are R-magnetized. The same polarity is known for basalts of the Kholbo Teg neck, dated as 18.5 ± 1 Ma, for the flows associated with it (14.8 ± 1 Ma), and for the basaltic flow in the Taishir Somon section along the Dzabkhan River (17.0 ± 1 Ma). Thus, the sedimentary sequence of the Ulan Tologoi Horizon, i.e., the Loh Formation, and basalts dated by K-Ar method and apparently corresponding in age to the upper, or possibly major part of the horizon, have the same R-magnetization. The radiometric age of the entire Ulan Tologoi Horizon may range in interval from 23 to 16 Ma (Devyatkin, 1981).

The middle part of the Miocene section (the upper subformation of the Oshin Formation) contains early *Hipparion* fauna. Paleomagnetic studies were carried out only in the lower part of the Khirgis Noor 2 section. The sediments have reversed polarity within the narrow normal zone in their upper part.

The upper part of the Miocene is represented by sediments of the Altan Teli Formation, and the lower part, by member A of the Khirgis Noor Formation. According to paleomagnetic data from the Khirgis Noor 2 section, this interval of the Neogene correlates to zones 5 - 7 of Cox's scale and corresponds to Tortonian and Messinian stages of the Upper Miocene in the Mediterranean (Pevzner *et al.*, 1982).

In general, deposits of the Altan Teli and Khirgis Noor formations are characterized by developed *Hipparion* fauna. Forms are represented by two lines: *Hiparrion theobaldi mogoicum–H. crassum–H. sefvei* and *Hipparion (Neohipparion) houfenense A–H.(N.) houfenense B* (Zhegallo, 1978). Rodents known from the lower subformation of the Khirgis Noor Formation are similar to forms from the Late Turolian (Pevzner *et al.*, 1982). Paleomagnetic and biostratigraphic data suggest the age of Altan Teli Formation and lower subformation of Khirgis Noor Formation to be 5 to 7 - 8 Ma (Devyatkin, 1981; Zhegallo, 1978; Pevzner *et al.*, 1982). It is significant that basalts in the Khangai (Orchon River valley), with K-Ar age of 6.4, 6.2, and 4.0 ± 0.5 Ma, have a stable R-magnetization and may correspond to Epoch 6 (two first dates) and the Gilbert Epoch (third date). Along the Chulutu River valley, basalts with K-Ar ages of $3.6 - 3.8 \pm 0.2$ Ma are R-magnetized, while basalts dated as 4.0 ± 0.25 Ma old have N-magnetization (Logochev *et al.*, 1982). The first two dates can be assigned to the upper part of the Gilbert Epoch, and the third one most likely corresponds to the Nunivak event (4.0 - 4.2 Ma).

Pliocene. Pliocene deposits are paleomagnetically studied in three sections, namely, Khirgis Noor 2, Chono-Khariakh, and Khung Kure. The uppermost part of member A and member B of Khirgis Noor Formation outcrop in these localities. In the stratotype section of member B there are two wide zones of reversed polarity and one zone of normal polarity. In the Chono-Khariakh and Khung Kure sections, two reversed and three normal polarity zones are recognized. This part of the Pliocene in Mongolia correlates to the Gilbert Epoch, which ranges in time from 3.2 to 5.2 Ma (Devyatkin, 1981; Pevzner *et al.*, 1982). It is possible to correlate normal magnetization zones registered in sections with the Sidufial (4.4 Ma), Nunivak (4.1 Ma), and Cochiti (3.7 Ma) events. Member B of the Khirgis Noor Formation contains developed *Hipparion* fauna with late forms of *H. houfenense*. *Proboscidipparion*; rodents *Promimomys* and *Aratomys*, and mastodons *Anancus sinensis* appear here for the first time. This part of the Pliocene sequence corresponds to the Kimmerian (Devyatkin, 1981), Ruscinian and Zanclean stages of the Mediterranean scale (Pevzner *et al.*, 1982).

Upper Pliocene deposits (the Shamar Formation) were paleomagnetically studied in sections of northern Mongolia. It was believed that deposits of this age contain the mammalian fauna of the Transbaicalian Chikoi Horizon (Devyatkin and Zazhigin, 1974; 1982). However, the material recently obtained by V.S. Zazhigin shows a presence of at least three biostratigraphic units of different ages. They can be correlated with the Moldavian (Orkhon 1 section, layer 8), Beteke (Ider section), and Chikoi (Shamar and Bural Obo sections) horizons. The age of the deposits in question is 3.3 - 1.8 Ma, which is deduced from their structural relations with effusives (Devyatkin, 1981). Deposits of the Orkhon 1 section (layer 8) containing rodents of the Moldavian Horizon have N-magnetization and correspond to the lower part of the Gauss Epoch, which is below the Mammoth event (3.05 Ma). There is no paleomagnetic data on the Ider section. In sections of Bural Obo, Shamar, and Shara Mankhatai that yielded Chikoi-type fauna, an alternation of reversed and normal polarity zones was established. The mammalian fauna was found in both zones. This part of the Pliocene sequence corresponds to the Matuyama Epoch, and to an event of normal polarity (Olduvai or Gilsa) inside the Epoch (Korina, 1974). The basalts underlaying the Upper Pliocene red deposits of the Shamar Horizon in the Orchon 1 section are dated as 3.2 ± 0.5 Ma old and have R-magnetization, similar to the basalts of the inset terrace (1.8 ± 0.1 Ma) (Devyatkin, 1981; Devyatkin and Smelov, 1979).

Anthropogene. It is most likely that the Tuin Gol Formation, which has the earliest horse and hipparion remnants, corresponds to the Eolpleistocene. There is no paleomagnetic data on this formation stratotype, and the exact time range of the formation is not defined. It has been suggested that it is younger than 1.8 Ma. However, in places the formation may have an older age, as it partly corresponds to the Shamar Horizon. Paleomagnetic studies were conducted in two sections. In the Khirgis Noor 2 section, the lower part of the formation is N-magnetized. The upper part of the formation here also has a normal polarity with a narrow reversed interval, dated by the TL method as 820 ± 85 ka. In the Kobdo section, deposits of the Tuin Gol Formation have a stable and persistent R-magnetization within the interval of TL ages from 1100 ± 120 to 800 ± 82 ka, i.e., they unambiguously correspond to the upper part of the Matuyama Epoch. These deposits correlate easily to the magnetostratigraphic scale of the Altai Mountains, where the Bashkaus and the upper part of the Beken Formations have a stable R-magnetization in the interval of TL ages from 625 ± 70 to 1500 ka, with a narrow zone of normal polarity (*Razrez* ..., 1978).

Regular paleomagnetic studies of the Pleistocene deposits of Mongolia have not been undertaken. Paleomagnetic analysis was carried out in a number of reference sections only. It was found that the Goshu Formation of the Lower Pleistocene in the Khung Kure section has R-magnetization in its lower part and N-magnetization in the upper. In the Khirgis Noor 2 section, this formation is mainly N-magnetized, but has a narrow zone of reversed polarity. Higher parts of the Pleistocene section are studied in the Chono-Khariakh locality. Here lacustrine clays dated by the TL method (320 ± 35 and 365 ± 42 ka) were found to be R-magnetized. It is possible that they correspond to the Biwa 3 event within the Bruhnes Epoch. In the Khirgis Noor 2 section, the lacustrine deposits of reversed polarity zone, and a TL age of 280 ± 40 ka, are also known. It is likely that this zone can be correlated with the Chagan event first recognized in the Altai Mountains (*Razrez* ..., 1978). A narrow zone of reversed polarity was found in glaciolacustrine clays of the Ulan Khus section in Kobdo River valley. It most likely corresponds to the Black event of the Bruhnes Epoch.

Naturally, the next step in the analysis of the first working version of the regional magnetostratigraphic scale of Mongolia should be its comparison to existing scales of this kind. The scale of Harland *et al.* (1982) was the chosen standard. A discussion of the Cretaceous and Paleocene parts of the sequence seems premature, as the samples from these intervals are incompletely studied.

The Khaitshin Horizon of the Middle-Upper Eocene (the time interval from 47 to 37 Ma) has a predominantly normal polarity in its lower part and a reversed polarity in its upper part, which, thus, establishes a certain similarity between the scales under comparison at the level of the Lutetian and Bartonian stages.

The Egelyeen Dzo Horizon of the Lower Eocene (time interval from 37 to 32 Ma) shows mainly a R-magnetization in lower part of the section and N-magnetization in the upper. A similar situation is observed in the reference scale at the level of Rupelian Stage.

The Shand Gol Horizon of the Middle-Upper Oligocene (32 - 23 Ma) is, of all the sections, the most completely characterized by paleomagnetic data and K-Ar ages. As in Harland's scale, it has variable magnetization and corresponds in general to the Europian Hattian Stage (Devyatkin, 1981). Basalts with ages between 28 and 32 Ma have normal polarity.

The Ulan Tologoi Horizon of the Lower-Middle Miocene (23 - 15 Ma) was studied using the paleomagnetic method in the Ulan Tologoi section, most likely ranging in time from 20 to 16 Ma. In general, the sequence is R-magnetized. The same was revealed for basalts with K-Ar ages of 18.9, 17.0, and 16.0 Ma. In Harland's reference scale, the entire interval under consideration varies in magnetization, but the intervals dated here principally coincide with reversed polarity zones. According to biostratigraphic, paleomagnetic, and radiometric data, the part of the Miocene sequence under study most likely corresponds to the Europe Burdigalian Stage (Devyatkin, 1981).

The correlation of the Upper Miocene and Pliocene sequences (Altan Teli and Khirgis Noor formations) with Cox's scale was previously given (Devyatkin, 1981; Pevzner *et al.*, 1982). As was established in the stratotype of Khirgis Noor Formation, this part of the

Reference points of radiometric (K-Ar) and thermoluminescence (TL) dating, and paleomagnetic studies in the territory of the Mongolia (K-Ar ages as Ma, TL ages as ka)

Sample no.	Location	Stratigraphic position	K-Ar or TL dates	Paleo-magnetic polarity	Position in the paleomag-netic scale
1	2	3	4	5	6
	Eocene				
1	Basaltic interlayer above the Khashat Formation	Beds with *Gomphas elcema* (Aguit Horizon?)	51 ± 2.0	normal	
	Oligocene				
2	Lower basaltic bed of the Shand Gol Formation	Shand Gol Horizon	31 ± 2.0	reversed	
3	Lower basaltic bed of the Shand Gol Formation	Shand Gol Horizon	32 ± 2.0	reversed	
4	Shand Gol (stratotype of the formation)	Shand Gol Horizon	30 ± 1.2	reversed	
5	Shand Gol (stratotype of the formation)	Shand Gol Horizon	28 ± 1.1	reversed	
6	Dzabkhan River, basaltic interlayer in the Boger Formation	Shand Gol Horizon	31 ± 1.2	reversed	
7	Upper basaltic bed of the Shand Gol Formation. Right bank of the Tatsin Gol River	Shand Gol Horizon	24 ± 1.0	reversed	
	Miocene				
8	Basaltic interlayer between the Shand Gol and Loh formations. Left bank of the Tuin Gol River	Ulan Tologoi Horizon	20 ± 0.5	reversed	
9	Basaltic bed above the Loh Formation. Left bank of the Tatsin Gol River, 10 km north of Tsagan Obo	Ulan Tologoi Horizon	18.9 ± 0.5	reversed	
10	The same, near Tsagan Obo	Ulan Tologoi Horizon	17.0 ± 2.0	reversed	
11	Repeated sample 9		16.0	reversed	
12	Lower basaltic flow at the base of a 90 m high terrace overlain by Pliocene deposits of the Orkhon River section	Altan Teli Horizon	6.2 ± 0.5	reversed	Epoch 6
13	6 km up stream of the Orkhon River.	same	6.4 ± 0.5	reversed	Epoch 6
	Pliocene				
14	Basalts at the base of a 120 m high terrace of the Orkhon River, in front of the Dulan Khara volcano	Khirgis Noor Horizon	4.0 ± 0.5	reversed	Gilbert Epoch
15	Basalts forming the middle part of a 255 m high terrace on the Chulutu River	Khirgis Noor Horizon (B)	4.0 ± 0.25	normal	Nunivak event (4.0 - 4.2 Ma)
16	Basalts forming the upper part of a 255 m high terrace of the Chulutu River	same	3.8 ± 0.2	normal	Gilbert Epoch, upper part
17	Basalts, 25 m over sample 16	same	3.6 ± 0.2	normal	
18	Upper basaltic bed of a 90 m high terrace of Orkhon River, underlied by Pliocene deposits	Shamar Horizon	3.2 ± 0.1	normal	Gauss Epoch (Mammuth event ?)
19	Basalts of a 15 m high terrace of the Orchon River	Tuin Gol Horizon	1.8 ± 0.1	normal	Matuyama Epoch (Gilsa subchron ?)
20	Basalts of upper part of a 120 m high terrace of the Orkhon River	same	1.5 ± 0.1	normal	Matuyama Epoch (Gilsa subchron ?)
21	Tuin Gol Formation in the Khirgis Noor section	same	820 ± 85 ka (TL)	reversed	Matuyama Epoch, upper part

(Contd.)

Sample no.	Location	Stratigraphic position	K-Ar or TL dates	Paleomagnetic polarity	Position in the paleomagnetic scale
1	2	3	4	5	6
22	Tuin Gol Formation in the Kobdo section	same	time span from 800 ± 80 to 1100 ± 120 ka (TL)	reversed	Matuyama Epoch, upper part
	Pleistocene				
23	Loams of Goshu Formation burnt by basalts from a section of a 75 m high terrace of the Chulutu River	Lower Pleistocene	520 ± 75 ka (TL)	normal	Bruhnes Epoch
24	Lacustrine clays of the Chono-Khariakh section over Pliocene deposits	Middle Pleistocene	time span from 320 to 360 ± 35 ka (TL)	reversed	Bruhnes Epoch (Biwa 3 event ?)
25	Lacustrine sands in the Khirgis Noor section	same	280 ± 29 ka	reversed	Bruhnes Epoch (Chagan event)
26	Lacustrine clays in the Ulan Khus section	Upper Pleistocene	105 ± 9 ka	reversed	Bruhnes Epoch (Black subchron)

sequence corresponds to the Gilbert Epoch, (Zones 5 and 6) thus having a time interval from 3.3 to 6.8 Ma. This is confirmed by radiometric dates ranging from 6.4 to 3.2 Ma. These horizons apparently correspond to the upper part of the Meotian, Pontian and Kimmerian in eastern Europe, and to the Messinian and Zanclean of the west European scale.

The Shamar Horizon of the Upper Pliocene is clearly restricted by age limits of 3.2 and 1.8 Ma. Paleomagnetic data suggests that it corresponds to the Gauss, and to the lower part of the Matuyama Epoch. Biostratigraphic materials correlate this horizon with the Akchagylian of the east European scale.

Paleomagnetic data on the Tuin Gol Horizon are fragmentary. Deposits of the horizon are reversely magnetized, and, according to the TL datings, range from 1.1 to 0.8 Ma. The horizon corresponds to the upper part of the Matuyama Epoch and most likely correlates with the second half of the Apsheronian.

As there was no paleomagnetic study of the entire Pleistocene sequence, only three registered events of reversed polarity rate mentioning. They are within the range of TL ages of 320 - 365 ± 40 ka (Biwa 3 event ?), 280 ± 40 ka (Chagan event), and 105 ± 9 ka (Black event) of the Bruhnes Epoch.

Further paleomagnetic studies on the territory of Mongolia should be concentrated on the other Cenozoic stratotypes and reference sections, and focus on still unstudied parts of the stratigraphic sequences, those of the Miocene and Pliocene in particular. For this stratigraphic interval, the clearest correlations with Cox's scale are possible and, thus, distant correlations are also possible.

Reference points of radiometric (K-Ar) and thermoluminecence datings, and paleomagnetic studies are given in the table.

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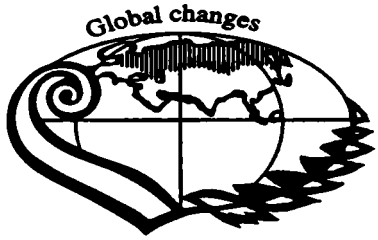

Evolution of the biosphere

Biogeographic and Climatic Peculiarities of Triassic Palynofloras from Eastern and Western Europe

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Abstract – Triassic palynofloras of Western and Eastern Europe are compared. The evolution of palynofloras shows their relation to phytogeographic and paleoclimatologic features, as well as to abiotic events, which occurred in the Triassic.

Results of palynology established the basis for the study of Triassic palynoflora peculiarities in Eastern and Western Europe. Nowadays the most well-known Triassic palynofloras from the East European platform are those from the sections of the Moscow, Pechora, and Caspian syneclises (Kyuntsel', 1965; Makarova, 1969, 1977; Sinegub, 1972; Pozemova, 1975; Varyukhina and Golubeva, 1983; Makarova and Romanovskaya, 1983; Goman'kov *et al.*, 1986; Shelekhova *et al.*, 1988; Yaroshenko, 1969; Yaroshenko *et al.*, 1991).

Palynospectra of the first half of the Early Triassic, presumably dated as the Indian, were recognized in grey beds of red terrigenous sequences of the Vokhma Horizon, the Moscow syneclise, as well as in the lower subformation of the Charkabozh Formation and in the Ershov Formation of the Pechora and Caspian syneclises, respectively. The presence of numerous diverse striate pollen of the *Striatites* group, together with non-striate forms and abundant *Cycadopites*, is common for the above-mentioned rock units. Assemblages of the Moscow and Caspian syneclises differed from those of the Pechora syneclise in the considerable importance of striate pollen in association with *Cycadopites* and *Gnetaceaepollenites*, as well as in the presence of pteridophyte spores and lycopods *Densoisporites* and *Kraeuselisporites*. Abundant pollen of that type in the former two regions rendered assemblages of the first half of the Lower Triassic similar to those of the Upper Permian. Palynoflora from the lower subformation of the Charkabozh Formation, the Pechora syneclise, yields both striate and monocolpate pollen, as well as pteridophyte spores, and is marked by numerous cavate spores of *Aratrisporites* and *Pechorosporites* together with *Densoisporites*, *Kraeuselisporites*, and *Lundbladispora*. The assemblage is also closely related to that of the Upper Permian, which, according to V.D. Tel'nova (Entsova *et al.*, 1974) contains abundant spores.

Palynofloras of the first half of the Lower Triassic from the East European platform, with a rich and diverse miospore composition, are similar to the "*Protohaploxypinus* and *Taeniaesporites assemblages*" from Otoceras beds in Cape Stosch, east Greenland (Balme, 1979), though the latter have a low taxonomic diversity. The earliest *Protohaploxypinus* assemblage yields striate pollen forms characteristic of the West European Zechstein. East European palynofloras are most similar to the assemblage of *Lundbladispora obsoleta–Protohaploxypinus pantii* Zone, which was found in the Lower Bunter in western Poland (Orłowska-Zwolinska, 1984). It also contains numerous *P. pantii* and other striate pollen taxa, typical of the Upper Permian, according to the author. Among this pollen, common lycopods *Lundbladispora*, *Densoisporites*, *Kraeuselisporites*, and pteridophyte spores were recorded.

Thus, the main feature of palynofloras of the first half of the Early Triassic both in the East European platform, and in regions under comparison, is the presence of numerous striate and non-striate pollen, similar to that of coniferous and pteridosperm plants. Also characteristic is the occurrence of pteridophyte and lycopod spores. The role of the latter increased in the second half of the Early Triassic. The resemblance of studied palynofloras most likely originated from similar paleogeographic conditions during the accumulation of continental deposits, represented by alluvial, alluvial-lacustrine, and lacustrine facies both in the East European platform and Western Europe. The climate was rather hot and sometimes arid, as indicated by the dominant red color of the rocks. Palynoflora of the Pechora syneclise, associated with similar facies, differs from other assemblages in the predominance of lycopod and pteridophyte spores, which is most likely the result of phytogeographic peculiarities of the

Angara paleofloral realm to which it belonged (Dobruskina, 1982; Meien, 1987).

Among the less diverse palynofloras of the second half of the Early Triassic, the palynoflora dominated by *Densoisporites nejburgii* with characteristic pteridophyte spores and *Taeniaesporites* (*Lunatisporites*) pollen was most important. Main finds of *D. nejburgii* spores referred to a lycopod *Pleuromeia* occur along with its remnants, and are known from deposits of the Rybinsk Horizon (Parshino beds), the Moscow syneclise, which were dated as the Early Olenekian (Neiburg, 1960; Kyuntsel', 1965; Dobruskina, 1974; Yaroshenko, 1975; Goman'kov *et al.*, 1986). A similar assemblage was recognized as well in the upper subformation of the Kuma Formation, eastern Cis-Caucasus region (Dobruskina, 1977; Aref'ev and Shelekhova, 1991). The great number of latter spores in deposits of the upper subformation of the Charkabozh Formation, the Pechora syneclise, is the basis for the assemblage with *D. nejburgii–Lundbladispora variabilis* from this unit (Yaroshenko *et al.*, 1991). The predominance of the same spores in the Middle Bunter enabled the recognition of the *D. nejburgii* Zone in western Poland (Orłowska-Zwolinska, 1984). *D. nejburgii* spores were also found in the younger deposits of the Olenekian Stage and its equivalents, where peaks of this species together with *Tirolites cassianus* and abundant spinose acritarchs were recorded, namely in the Bogdo Formation, Bol'shoe Bogdo Mountain (Sinegub, 1972); and the Spathian beds in the Italian Dolomite Alps (Visscher, 1974); as well as in the upper part of the Middle Bunter in the German basin (Schulz, 1964; Reitz, 1985). Finds of abundant *D. nejburgii* spores with numerous spinose acritarchs from the base of the Acheshbok Formation in the Tkhach River section, western Caucasus, suggest a Late Olenekian age of the deposits (Yaroshenko, 1978). The wide distribution of *D. nejburgii* and *Pleuromeia* macrofossils coincided with the vast Olenekian transgression, which occurred synchronously both in the Boreal and Tethian regions (*Verkhnepermskie* ..., 1984; Lozovskii, 1991). This fact indicates an important abiotic event. Accumulations of macro- and microremnants of these lycopods both in alluvial-lacustrine and lacustrine facies, widely represented in the East European platform, as well as in deposits of Tethian and Boreal coastal regions (Dobruskina, 1982) do not appear to be accidental.

Palynofloras of the East European platform and Western Europe changed essentially in the Middle Triassic, especially in its second half. The Middle Triassic, presumably the Anisian, miospore assemblages from the East European platform were marked by the occurrence of numerous *Disaccites* pollen, represented by *Illinites chitonoides* Klaus, *Voltziaceaesporites heteromorpha* Klaus, *Angustisulcites klausi* Freud., *Microcachryidites* spp., *Colpectopollis* sp., and *Minutosaccus* spp., in association with diverse and distinctive pteridophyte spores of *Concentrisporites*, *Perotrilites*, and *Duplexisporites*, scarce striate pollen, and single *D. nejburgii*. Quantitative proportions between pollen and spores in palynospectra of the Pechora and Caspian syneclises are nearly equal (Golubeva, 1979; Makarova, 1969; Pozemova, 1975). A similar taxonomic composition was recorded in assemblages of the Lower and Middle Muschelkalk in Western Europe, namely, in France (Taugourdeau-Lantz, 1974, 1983; Doubinger and Adloff, 1981; Adloff *et al.*, 1982), the Netherlands (Visscher and Commissaris, 1968), and Germany (Reitz, 1985), though these spectra differ from those of Eastern Europe by the predominance of pollen. Among the latter *Microcachryidites* and *Triadispora* are dominant and associated with scarcer *Illinites*, *Voltziaceaesporites*, and *Angustisulcites*, and distinctive pteridophyte spores.

The miospore composition is essentially different in the palynoflora of the Upper Muschelkalk, considered as an equivalent of the Ladinian, presumably, of its lower part. The pollen genus *Minutosaccus* became important, and a distinctive monosaccate pollen *Heliosaccus dimorphus* Madler appeared here. This palynoflora is distinct because of the abundant spores of the lycopod *Aratrisporites* associated with characteristic spores, which are more numerous and diverse in the Lower Keuper sediments (Orłowska-Zwolinska, 1977; Duringer and Doubinger, 1985; Reitz, 1985). The occurrence of abundant acritarchs, indicative of a marine transgression (Reitz, 1985), is another peculiarity of the palynoflora from the Upper Muschelkalk.

An analogous palynoflora was found in the Caspian syneclise sections of the East European platform, where it also contains abundant spores of *Aratrisporites*. The assemblage additionally contains higher amount of *Leschikisporis aduncus* (Lesch.) Pot., *Converrucosisporites* spp., and *Keuperisporites baculatus* Schulz, along with single *Kuglerina meieri* Scheur. and *Paracirculina scurrilis* Scheur., and, most importantly, the key taxa *Heliosaccus dimorphus* (= *Accinctisporites*, Yaroshenko, 1969) and *Echinitosporites iliacoides* Schulz et Krutzsch, whose stratigraphic range is limited by the Ladinian in the Alpine facies (Visscher and Brugman, 1981; Van der Eem, 1983). This palynoflora is similar to the West European assemblages also in the occurrence of abundant acritarchs *Micrhystridium*, *Veryhachium*, and *Leiosphaeridium*. The occurrence of the latter coincides with a vast ostracode invasion, which indicates a marine transgression in the Caspian syneclise at the end of the Middle Triassic (Lipatova, 1982).

In the Upper Triassic palynoflora, the taxa surviving from the Ladinian still occur, except for *Heliosaccus dimorphus* and *Echinitosporites iliacoides*. However, the following characteristic miospores are most important in assemblages of that age: *Camarozonosporites rudis* (Leschik) Klaus, *Lycopodiacidites kuepperi* Klaus, *Zebrasporites kahleri* Klaus, *Kraeuselisporites cooksonae* (Leschik) Jans., *Ovalipollis pseudoalatus* (Thierg.) Schuurman, and *Chasmatosporites apertus* (Rog.) Nilsson, single *Granuloperculatipollis* and *Corollina*, as well as abundant Dipteridaceae spores. Most of these miospores were recorded in palynofloras from both the Alpine (Bharadwaj and Singh, 1964) and

German facies (Klaus, 1960; Kavary, 1972; Dunay and Fisher, 1978; Scheuring, 1978; Orłowska-Zwolinska, 1983; Reitz, 1985). In the meantime, the above-mentioned taxa, along with pollen of the *Triadispora* and *Circumpolles* groups, became most important in some Carnian palynofloras of West European origin. Representatives of the latter still appeared in the Ladinian.

The Ladinian–Carnian palynofloras of southern Spain were even more peculiar (Besems, 1982, 1983). As important components they include along with *Ovalipollis*, protomonosaccate and monosaccate pollen of *Kuglerina meieri*, *Patinasporites densus* Lesch., and *Vallasporites ignaci* Lesch., and also pollen of the *Triadispora* and *Circumpolles* groups, i.e., of xerophilous plants characteristic of an arid climate (Visscher and Van der Zwan, 1981). Arid paleoenvirouments in Spain are evident also from the lithology of carbonate and red deposits contrasting with grey terrigenous sediments of the Caspian syneclise, where xerophilous plants were absent or occurred sporadically, indicating a more temperate and humid climate.

Like the Ladinian, the studied Late Triassic palynofloras from the Caspian syneclise and Western Europe are related to the Euro-Sinian paleoflora realm (Dobruskina, 1982; Meien, 1987), and generally contain similar miospore assemblages. At the same time, the phytogeographic localization resulted in certain differences between them, as the former palynoflora originated in Central Asia, but the latter in the European province of a more arid climate, especially in the regions adjacent to the Mediterranean.

In conclusion, we should note that, in spite of facies or phytogeographic variations, the studied palynofloras reveal successive assemblages as a result of evolution. The latter was likely related to evolutionary stages of both marine and continental biotas, reflecting the sedimentary basins' development (*Verkhnepermskie ...*, 1984; Lozovskii, 1991; Bilal *et al.*, 1987). So, the mass appearance of lycopod spores of Pleuromeia plants, belonging to the *Densoisporites* genus in the second half of the Early Triassic, and then of *Aratrisporites* specimens together with acritarchs in the Ladinian, occurred each time simultaneously on the East European platform and in Western Europe, corresponding to the Olenekian and Ladinian transgressions, respectively. The transgressions were large-scale abiotic events, associated with the eustatic fluctuations of the global sea level (*Verkhnepermskie ...*, 1984; Lozovskii, 1991).

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Comparative Analysis of the Tithonian Foraminifers of the Crimea and Syria

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Abstract – The following is the result of the study of the Tithonian foraminifers derived from terrigenous and carbonate facies of the Crimea and Syria. The highest taxonomic diversity of the assemblages is recorded from the terrigenous deposits of the Crimea. The carbonate facies of this region are characterized by less diverse assemblages, which are dominated by large Lituolidae with a complex alveolar wall structure. The deposits in Syria show a similar relationship between the facies, however the taxonomic composition of the thanatocoenoses is impoverished there. Paleobiogeographically, foraminiferal assemblages of these regions comprise the Tethyan tropical endemics (Syria), Subtethyan subtropical forms (the Crimea and Syria), and widespread boreal-cosmopolitan elements. By taxonomic diversity, the latters reach 94% in the Crimea and 60% in Syria, however they are not dominant with regard to population density. The tropical endemics dominate in the Tithonian of Syria and the subtropical forms prevail in the Crimea. Endemism of the Tithonian benthic foraminiferal assemblages appears at the family and genus level (2 families and 5 genera). According to dominant groups, the Tethyan foraminiferal fauna of the cyclamminid-pfenderinid type can be divided into two subtypes. The cyclamminid-trocholinid subtype is peculiar to the carbonate facies of the Crimea, and the cyclamminid-pfenderinid subtype is typical of the Tithonian of Syria.

The final developmental stage of the Jurassic sea basins inside the Mesozoic Tethys ocean as well as their biota is of special paleontological and stratigraphical interest. The stage is related to the beginning of drastic changes in many biotic groups and abiotic parameters of the basins, such as structure, sizes, depths, types of sedimentogenesis, and others.

Ample material collected from the Tithonian of the Crimea and Middle East (Syria) in the course of long-term field investigations allows us to compare the foraminiferal assemblages that inhabited the northern margin of the Tethys (the Subtethyan type of foraminiferal fauna spread throughout the Crimea) and the tropical water zone (the Tethyan faunal type peculiar to Syria and adjacent countries of the east Mediterranean).

It seemed necessary to study the taxonomical composition and structure of the assemblages, the extent to which they are affected by abiotic factors, the confinement of certain assemblages to certain basin zones and facies, degree of endemism, and so on.

The available materials were of different values. Almost all the Crimean sequences of both carbonate and terrigenous Tithonian sediments were sampled. Foraminifers were studied from thin sections and in residues. So, we had a full picture of the evolution of the Tithonian foraminiferal assemblages in the Crimea. The Syrian material was less abundant and thorough because of the sporadic and mosaic distribution of the Tithonian sections there. Separate outcrops, 2 - 30 m thick, are located mostly in the southwestern region of the country, in the Anti-Lebanon Mountains. The Tithonian sediments are represented there by carbonate clays and loose chalk-like marls with thin interbeds of predominantly aphanitic, rare bioclastic, and oolitic-detrital limestones.

We studied the Tithonian strata of the Quadmous section in the Coastal Mountains, western Syria, where they were earlier considered to be missing. The Tithonian strata are unconformably underlain by the Callovian deposits and are represented by carbonate clays with thin limestone interbeds. No Tithonian deposits have been found in central Syria, the Palmyrids, and in the north, the Kurd Dag.

Thus, we studied the Tithonian deposits and foraminifers from two localities and four sections only. Nearly 30 samples were collected.

In spite of the fact that the Crimean material characterizes the studied stratigraphical interval much better, a comparative analysis of the Tithonian foraminifers of the Crimea and Syria is of interest because these territories were located at that time inside the single Mesozoic Tethys ocean. However, the assemblages were formed in basins differing in many peculiarities (Table 1).

From the Tithonian through Berriasian, the recent territories of the Crimea and Syria were parts of a single extensive Mediterranean basin. These water areas were located nearly at the same longitude, but their latitudinal positions were different. On recent geographic maps the Crimea and Syria are located in the longitudinal range of 33° - 36°E, the Crimea in the latitudinal range of 43° - 45°N and Syria in the latitudinal range of

Table 1. Characteristics of the Tithonian deposits of the Crimea and Syria

	The Crimea	Syria
Location of a region in the Tethys ocean	Northern margin. Subtropical realm	Southern margin realm
Distribution	Universal, in the area of distribution of Jurassic sediments	Limited, mosaic. The southwest of Syria, Anti-Lebanon, a central part of the Coastal Mountains
Lithological composition	Pelitomorphic, bioclastic and oncolitic limestones; carbonate clays; flyschoid alternation of clays, siltstones, and limestones	Carbonate clays, clayey marls, aphanitic and bioclastic limestones
Thickness	Up to 3500 m	Up to 80 m
Paleobasin zones	Carbonate platform. Upper and lower sublittoral zone	Carbonate platform. Upper and lower sublittoral zone

33° - 35°N. The geographic position and climatic conditions of these regions determined both similarites and differences between their biotas. Syria was located in the southern part of the Mediterranean area of the Tethyan realm, whereas the Crimea belonged to the northern margin of the area. The Tithonian and Berriasian foraminiferal fauna of Syria can be referred to the Tethyan type and that of the Crimea to the Subtethyan one (Gorbachik and Kuznetsova, 1991).

TITHONIAN OF THE CRIMEA

The Tithonian deposits are distributed widely over the peninsula and show high facies variation. In the western and central parts of the Main Range of the Crimean Mountains, these deposits are mainly represented by limestones (Fig. 1). These are carbonate platform deposits typical of the Tithonian and partly Berriasian of the Mediterranean area of the Tethyan realm. The Tithonian strata were accumulated in the warm shallow-water basin and contain oyster banks, remains of corals, rudistes, gastropods, echinoids, various algae, and foraminifers. The Tithonian shows a variety of limestones – from cryptocrystalline and pelitomorphic to bioclastic, brecciated, reef, oncolitic, and oncolitic-detrital.

In the southwestern Crimea, near the village of Druzhnoe, the Tithonian limestones include numerous conglomerate interbeds, 1 m thick, corresponding to erosional levels and indicating near coastal environments. Interbeds of marlaceous limestones also occur. In the Ai-Petri Yaila region, the Lower Tithonian strata locally include some members of bioclastic limestones containing an abundant presence of the large foraminifers *Anchispirocyclina lusitanica* (Egger) (Mamontova, 1976). The Upper Tithonian strata are exposed in this region, along the Sokolinoe–Ai-Petri road and above the upper parts of the Great Canyon. There the bioclastic limestones show marlaceous interbeds rich in tests of this species. The compact bioclastic limestones contain also abundant remains of dasycladares, including *Kopetdagaria iailensis* Maslov.

Other Tithonian facies are peculiar to the east Crimean synclinorium, which exhibits a predominantly flyschoid alternation of siltstones, clays, and brecciated clastic limestones as well as sandstones and conglomerates.

A thick member of flyschoid alternation is characteristic of the Tithonian of the Theodosia City region (Kuznetsova and Gorbachik, 1985). The Upper Tithonian carbonate facies, which are as rich in tests of *Anchispirocyclina lusitanica* as the limestones and marls of the southwestern Crimea, were recovered in the Tambov-1 and Tambov-3 wells, 13 km northwest of the city of Theodosia (Voloshina, 1974, 1976). The thickness of the Tithonian deposits in the Crimea ranges from a few hundred to 1500 - 3500 m. These deposits rest unconformably on the Kimmeridgian and even Oxfordian strata.

Based on the evolution of ammonite, Uspenskaya (1969) subdivided the Tithonian Stage of the Crimea into two substages, as opposed to the threefold division accepted in Western Europe. She distinguished the *Kossmatia richteri–Glochiceras litographicus* Zone in the Lower Tithonian and the *Virgatosphinctes transitorius* Zone in the Upper Tithonian. According to foraminiferal records, the Lower Tithonian corresponds to the beds with *Epistomina ventriosa–Textularia densa*, and the Upper Tithonian to the *Astacolus laudatus–Epistomina omninoreticulata* Zone and the *Anchispyrocyclina lusitanica–Melatrokerion spirialis* Zone (Kuznetsova and Gorbachik, 1985).

A comparative analysis shows higher taxonomic diversity of foraminifers from the terrigenous rocks than from the carbonate rocks. The carbonate facies contain mainly Lituolidae with a complex wall of test, Involutinidae (genus *Trocholina*), small Ataxophragmiidae and Textulariidae, rare Miliolidae, Lagenidae, and Epistominidae.

Noteworthy, foraminiferal diversity and abundance vary with different samples from the same facies. The highest abundance is recorded in carbonate clay and biogenic limestone, particularly, in loose interbeds within the latter. These interbeds contain abundant tests of so called "larger" foraminifers, several milimeters to

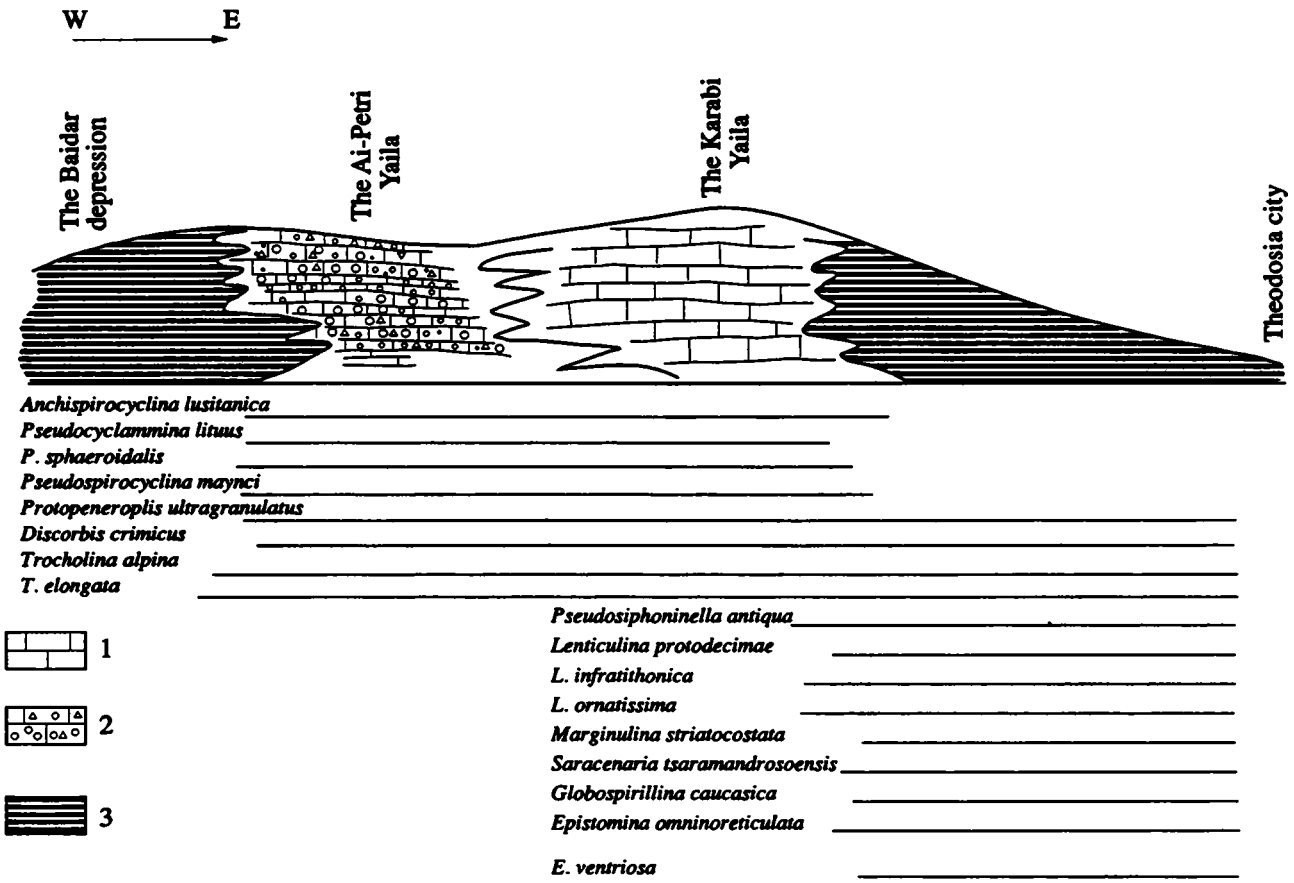

Fig. 1. Scheme of relationship between of the Tithonian facies in the Mountain Crimea (after Muratov, 1960).
1 – Limestones; 2 – breccia-like limestones; 3 – clays.

even 1 or 2 cm in size. Tests of Lituilidae with a complex wall (*Anchispirocyclina* and *Rectocyclammina*) and of the genera *Ammobaculites* and *Trocholina* run into hundreds and tens of hundreds of specimens.

The number of tests in a sample from clayey rocks of the flyschoid strata ranges from a few to several dozen. No genus or species predominates, but in some cases representatives of the genera *Epistomina*, *Lenticulina*, and *Trocholina* are present in abundance. Generally, "smaller" foraminifers, 0.3 - 0.5 mm in size on average, are distributed throughout. Large Lituolidae with a complex wall of test are missing.

TITHONIAN OF SYRIA

The Tithonian sediments are preserved in Syria in single sections only, because the pre-Cretaceous uplifts embraced the largest part of its territory. We studied them in Anti-Lebanon (the Wadi Al-Karn, Sad Al-Karn, and Wadi Favuar sections) and the Coastal Mountains (the Qadmous section). The most diverse and abundant foraminiferal assemblages from these sediments include the widespread species-indexes of the *Anchispirocyclina lusitanica* (Egger)–*Melathrokerion eospirialis* (Gorb). Zone. This zone is distinguished in the Tithonian of Syria, the Crimea, Caucasus, and probably Morocco. Lack of the complete Tithonian sections in Syria prevents a more detailed subdivision. The Tithonian foraminiferal assemblages from Anti-Lebanon are characterized by a mixed composition including both the Tethyan and Subtethyan endemics and cosmopolitan forms. The following assemblage was found there: *Gaudryina vadazi* Cushm. et Glaz., *Stomatostoecha compressa* Gorb., *Melathrokerion eospirialis* Gorb., *Alveosepta powersi* Redm., *Verneuilina angularis* Gorb., *Marssonella hehti* Dieni et Mass., *Anchispirocyclina lusitanica* (Egger), *Pseudocyclammina* sp. and *Kurnubia jurassica* Redm (Table 3).

The Qadmous section in the Coastal Mountains yielded another assemblage dominated by the Tethyan endemics *Bramkampella arabica* Redm. and Subtethyan species *Choffatella decipiens* Schlum., *Anchispirocyclina lusitanica* (Egger), *Pseudocyclammina parvula* Hoff., *Feurtillia frequens* Maync and *Torinosuella* sp.

This assemblage, which is present in great numbers, includes both the proper Tithonian forms and the forms that appeared in the Tithonian and continued to exist in the Cretaceous. Apparently, the uppermost Jurassic

Table 2. Taxonomic composition of foraminifers from the Tithonian of the Crimea and Syria

Family, genus	Number of species		Family, genus	Number of species	
	the Crimea	Syria		the Crimea	Syria
Saccamminidae			Textulariidae		
Saccammina	1		*Textularia*	1	1
Rhizamminidae			Involutinidae		
Rhizammina	1		*Globospirillina*	2	2
Ammodiscidae			Trocholinidae		
Glomospira	1		*Trocholina*	8	1
Glomospirella	1		Ventrolaminidae		
Reophcidae			*Protopeneroplis*	1	
Reophax	3	2	Ophthalmidiidae		
Haplophragmoididae			*Ophthalmidium*	1	
Haplophragmoides	3	2	Hauerinidae		
Evolutinella		1	*Quinqueloculina*	1	1
Lituolidae			*Pseudosigmoilina*		1
Ammobaculites	2	1	Spirillinidae		
Triplasia	1	1	*Spirillina*	2	2
Nautiloculinidae		1	*Trochospirillina*	1	1
Nautiloculina			*Conicospirillina*		1
Mayncinidae		1	Patellinidae		
Phenacophragma		1	*Patellina*	2	2
Stomatostoecha	2	1	Nodosariidae		
Placopsilinidae			*Nodosaria*	3	2
Acruliammina	1		*Lagena*	2	
Ammosphaeroidinidae			*Dentalina*	5	
Recurvoides		1	*Pseudonodosaria*	5	
Haplophragmiidae			*Lingulina*		2
Haplophragmium	3	2	*Tristix*	1	
Charentiidae			*Frondicularia*	2	
Charentia	1	1	Lenticulinidae		
Melathrokerion	2	2	*Lenticulina*	18	3
Cyclamminidae			*Astacolus*	5	1
Bramkampella	1	1	*Saranacenaria*	3	1
Pseudocyclammina	2	4	Vaginulinidae		
Choffatella		1	*Citharina*	2	1
Torinosuella		1	*Vaginulina*	2	
Rectocyclammina	1	1	*Marginulina*	2	
Everticyclammina	1	1	*Marginulinita*	1	
Mesoendothyridae			Polymorphinidae		
Feurtillia	1	1	*Bullopora*	1	1
Alveosepta		1	*Guttulina*	1	2
Spirocyclinidae			*Eoguttulina*	1	3
Pseudospirocyclina	1	1	*Globulina*	1	3
Anchispirocyclina	1	1	*Ramulina*	4	1
Trochamminidae			Conorboididae		
Trochammina	3		*Conorboides*	1	1
Dorothiidae			Ceratobuliminidae		
Marssonella	1	2	*Pseudolamarckina*	1	
Dorothia	1	1	*Pseudosiphoninella*	1	
Pfenderinidae			Epistominidae		
Kurnubia		1	*Epistomina*	2	2
Verneuilinidae			Discorbidae?		
Verneuilina	2	2	*Discorbis?*	4	1
Belorussiella	1	1	Buliminidae		
Tritaxiidae			*Neobulimina*	1	
Tritaxia	1	1			

Table 3. Distribution of foraminifers in the Tithonian deposits of the Crimea and Syria

Upper Jurassic		Lower Cretaceous	Genera and species of foraminifera
Kimmeridgian	Tithonian	Berriasian	
			Saccammina sp.
			Rhizammina indivisa Brady
			Glomospira gordialis Parker et Jones
			Glomospirella gaultina (Berth.)
			Reophax hounstoutensis Lloyd
			R. praestellatus Gorb.
			R. stellatus Neaqu
			Haplophragmoides nonioninoides Reuss
			H. subaequalis Mjatl.
			H. globigerinoides (Haeusler)
			H. volubilis Romanova
			Ammobaculites gracilis Bart. et Br.
			A. inconstans inconstans Bart. et Br.
			Triplasia elegans Mjatl.
			Recurvoides limbatus Chapm.
			Nautiloculina oolithica Mohl.
			Phenacophragma sp.
			Stomatostoecha compressa Gorb.
			S. enisalensis Gorb.
			Haplophragmium elongatulum Dain
			H. lutzei Hanzl.
			H. montratus (Dain)
			Charentia evoluta (Gorb.)
			Melathrokerion spirialis Gorb.
			M. eospirialis Gorb.
			Bramkampella arabica Redm.
			Pseudocyclammina lituus Yokoyama
			P. parvula Hott.
			P. sphaeroidalis Hott.
			P. sulajana Redm.
			Rectocyclammina chouberti Hott.
			Everticyclammina aff. *greigi* (Henson)
			Choffatella decipiens Schlum.
			Torinosuella peneropliformis Yabe et Hanzawa
			Mesoendothyra croatica Gusiĉ
			Feurtillia frequens Maync
			Alveosepta powersi (Redm.)
			Anchispirocyclina lusitanica (Egger)
			Pseudospirocyclina maynci Hott.
			Trochammina nitida Brady
			T. globigeriniformis (Park. et Jon.)
			T. neocomiana Mjatl.
			Marssonella doneziana Dain
			M. hehti Dieni et Mass.

Table 3. (Contd.)

Upper Jurassic		Lower Cretaceous	Genera and species of foraminifera
Kimmeridgian	Tithonian	Berriasian	
			M. oxycona Reuss
			Dorothia praehauteriviana Dieni et Mass.
			Kurnubia jurassica Redm.
			Verneuilina angularis Gorb.
			V. subminuta Gorb.
			Belorussiella taurica Gorb.
			Tritaxia pyramidata Reuss.
			Gaudryina vadazi Cushm. et Glaz.
			Textularia crimica (Gorb.)
			T. densa Hoffm.
			Globospirillina caucasica (Hoffm)
			G. neocomiana (Moullade)
			Trocholina alpina (Leup.)
			T. elongata (Leup.)
			T. solecensis Biel. et Pož.
			T. infragranulata Noth
			T. companella Arnaud
			T. molesta Gorb.
			T. micra Dulub
			T. delphinensis Arnaud
			Protopeneroplis ultragranulatus Gorb.
			Ophthalmidium sigmoiliformis Ant.
			Quenqueloculina egmontensis Lloyd
			Pseudosigmoilina miliolinformis (Paalz.)
			Spirillina elongata Biel. et Pož.
			S. kubleri Mjatl.
			Trochospirillina amoena Dain
			Conicospirillina basiliensis Mohler
			Patellina subcretacea Cushm. et Alex.
			P. turriculata Dieni et Mass.
			P. feifeli (Paalz.)
			Lagena alata Reuss
			L. sztejnae Dieni et Mass.
			Nodosaria pseudohispida Gerke
			N. paupercula Reuss
			Dentalina sublinearis Schw.
			D. lequmen Reuss
			D. communis Reuss
			D. pseudocommunis Franke
			D. marginulcides Reuss
			Pseudonodosaria humilis (Roem.)
			P. diversa (Hoff.)
			P. laevigata (Orb.)
			P. brandy Tappan

Table 3. (Contd.)

Upper Jurassic		Lower Cretaceous	Genera and species of foraminifera
Kimmeridgian	Tithonian	Berriasian	
			P. tutkovskii (Mjatl.)
			Tristix temirica (Dain)
			Lenticulina undorica K. Kuzn.
			L. macra Gorb.
			L. infravolgensis (Furss et Pol.)
			L. tsaramondrosoensis Esp. et Sig.
			L. polygonata (Franke)
			L. saxonica bifurcilla Bart. et Brand
			L. subalata Reuss
			L. selecta K. Kuzn.
			L. protodecimae Dieni et Mass.
			L. pschehaensis Hoff.
			L. collignoni Esp. et Sig.
			L. aff. *karlaensis* Dain
			L. perrara K. Kuzn.
			L. nodosa (Reuss)
			L. dilecta Putria
			L. biexcavata (Mjatl.)
			L. ornatissima (Furss. et Pol.)
			L. andromedae Esp. et Sig.
			L. vistulae Biel et Pož.
			Astacollus planiusculus (Reuss)
			A. major Bornemann
			A. incurvatus (Reuss)
			A. bronni (Roem.)
			A. calliopsis (Reuss)
			A. laudatus (Hoff.)
			Saracenaria invenusta Putrja
			S. tsaramondrosoensis Esp. et Sig.
			S. pravoslavlevi Furss. et Pol.
			Planularia poljenovae K. Kuzn.
			P. tricarinella (Reuss)
			Citharina paucicostata (Reuss)
			C. raricostata (Furss. et Pol.)
			C. flabellata (Gumb.)
			Vaginulina incurvata Reuss
			V. denudata Reuss
			Frondicularia crimica Schokh.
			F. cuspidiata Pathy
			Marginulinita pyramidalis (Koch.)
			Marginulina distorta K. Kuzn.
			M. striatocostata Reuss
			Gutullina micra Tairov
			Eoguttulina biffida Dain

Table 3. (Contd.)

Upper Jurassic		Lower Cretaceous	Genera and species of foraminifera
Kimmeridgian	Tithonian	Berriasian	
			Bullopora rostrata Quenst.
			Ramulina nodosarioides Dain
			R. spandeli Paalz.
			R. aculeata Orb.
			R. spinata Anton
			Conorboides valandisensis (Bart. et Br.)
			Discorbis ? praelongus Gorb
			Pseudolamarckina reussi (Ant.)
			Epistomina omninoreticulata Esp. et Sig.
			E. ventriosa Esp. et Sig.
			E. gorodistchensis Dain, K. Kuzn.
			Discrobis miser Gorb.
			D. crimicus Schokh.
			D. infracretaceous Schokh.
			D. agalarovae Anton
			Pseudosiphoninella antiqua (Gorb.)
			Neobulimina inversa Anton.

——— distribution of foraminifers in the Crimea.

~~~ the same in Syria.

deposits – the Upper Tithonian and the beds transitional to the Berriasian – are preserved in this section.

When comparing the foraminiferal assemblages from the Tithonian of the Crimea and Syria (Table 2), we should, to account for inequalities between the materials, indicate distinctions in the taxonomic diversity rather than quantitative ones (Fig. 2).

These distinctions are recorded at levels of families, genera, and species (Table 3). The most dramatic difference is that species of the typical Tethyan family Pfenderinidae are missing in the Tithonian of the Crimea, whereas the Syrian material exhibits abundant *Kurnubia jurassica* Redmond belonging to this family. Occurrence of Kurnubia in the Tithonian of the Crimea

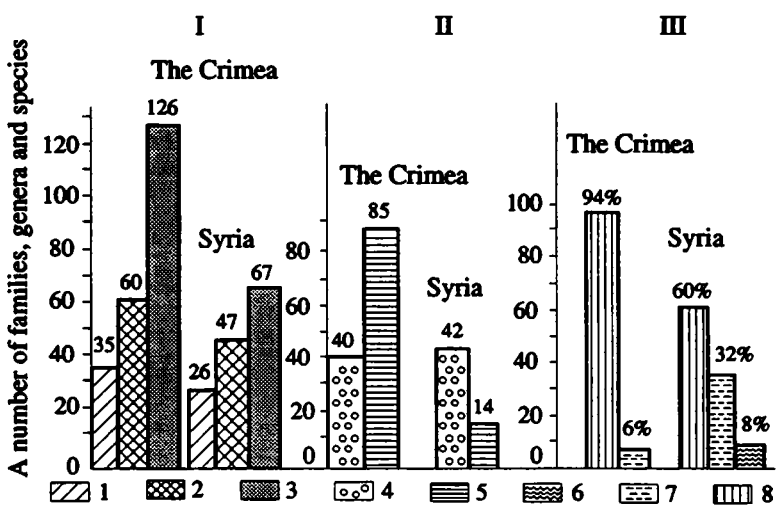

Fig. 2. Relationship between taxonomic, ecological and paleobiogeographical components of the Tithonian foraminiferal thanatocoenoses in the Crimea and Syria.

I – Families, genera and species of foraminifera; II – agglutinated and secretory benthic foraminifera; III – Tethyan, Subtethyan and boreal-cosmopolitan forms. 1 – families; 2 – genera; 3 – species; 4 – agglutinating foraminifers; 5 – secreting foraminifers; 6 – Tethyan; 7 – Subtethyan; 8 – boreal-cosmopolitan.
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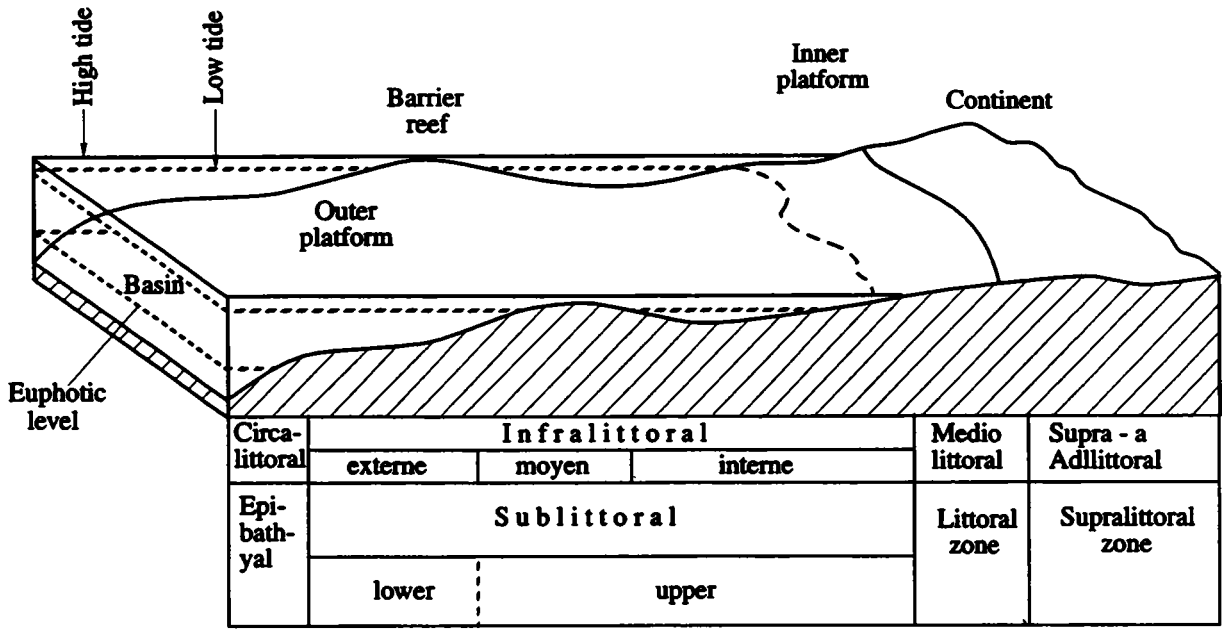

Fig. 3. A model for a carbonate platform basin (after Pelissié, Peybernés and Rey, 1984) with modifications.

was mentioned only in Dulub and Zhabina (1993), who presented a cross section of a "test" named *Kurnubia* aff. *palastinensis* Henson (Plate III, Fig. 3) from the Kimmeridgian–Tithonian of the southeastern Crimea (the Uzhno-Vidnensk-1 Well). However, its identification is very doubtful, because, by structure and sizes, the described object can be referred just as well to algae or hydroids.

The second important difference is the absence of such genera of the Cyclamminidae family as *Torinosiella* and *Choffatella* in the Tithonian of the Crimea wheras *Torinosuella peneropliformis* (Yabe et Hanzawa) and abundant *Choffatella decipiens* Schlumberger occur in the Tithonian of Syria.

The genus *Alveosepta* (the family Mesoendothiridae), which is represented by abundant *Alveosepta powersi* (Redmond) in Syria, was also absent from the Crimean material.

When studying numerous thin sections of the limestones and samples from the loose Tithonian rocks of the Crimea, we did not find *Nautiloculina oolithica* Mohler, which is typical of the family Nautiloculinidae and peculiar to the Jurassic of the central and east Mediterranean. An equatorial section of tests of this species resembles slightly that of *Melathrokerion spirialis* Gorbatchik, differing in lower whorls, a greater amount of whorls and chambers, and straight short thick septa. Perhaps, because of this resemblance, Dulub and Zhabina recorded an occurrence of *N. oolithica* in the Tithonian and Berriasian of the Crimea and represented *M. spirialis* under this name (Dulub and Zhabina, 1993, Plate I, Fig. 4).

A distinctive feature of the Tithonian of the Crimea as compared with Syria is the high diversity of representatives of the order Lagenida (families Nodosariidae, Lenticulinidae, Vaginulinidae, and Polymorphinidae), which were adapted mainly to terrigenous facies.

The relationship between taxonomical, ecological, and paleobiogeographical components in the Tithonian thanatocoenoses (Fig. 2) suggests that the benthic assemblages from the Crimea are dominated by forms with secretory tests, while agglutinated forms prevail in Syria. However, this is typical mainly of the terrigenous facies of the Crimea. The carbonate deposits predominantly yield forms with agglutinated tests. The following regularity characterizes the distribution of terrigenous, terrigenous-carbonate, and purely carbonate facies and related foraminiferal assemblages in the Crimea Mountains.

The carbonate deposits of the Crimea Mountains contain foraminiferal assemblages, which are dominated by or include a great amount of forms with agglutinated tests of the Cyclamminidae family [*Anchispirocyclina lusitanica* (Egger), *Preudocyclammina lituus* Yokoyama, *P. sphaeroidalis* Hottinger, and *Pseudospirocyclina maynci* Hottinger (Fig. 3)]. An important distinctive feature of these species is a complex alveolar wall structure. These species are referred to the Subtethyan foraminiferal fauna, which we recognize as a separate cyclamminid-trocholinid subtype of the cyclamminid-pfenderinid type of the Tethyan foraminiferal fauna (Basov, 1974; Basov *et al.*, 1972; Kuznetsova and Gorbachik, 1985; Gorbachik and Kuznetsova, 1991).

This assemblage most likely inhabited the upper sublittoral zone of the shallow warm-water basin of the carbonate platform. The assemblage includes abundant *Trocholina* and *Discorbis*, which spread over the basin wider than Cyclamminidae and occur in the deeper water terrigenous sediments of the lower sublittoral

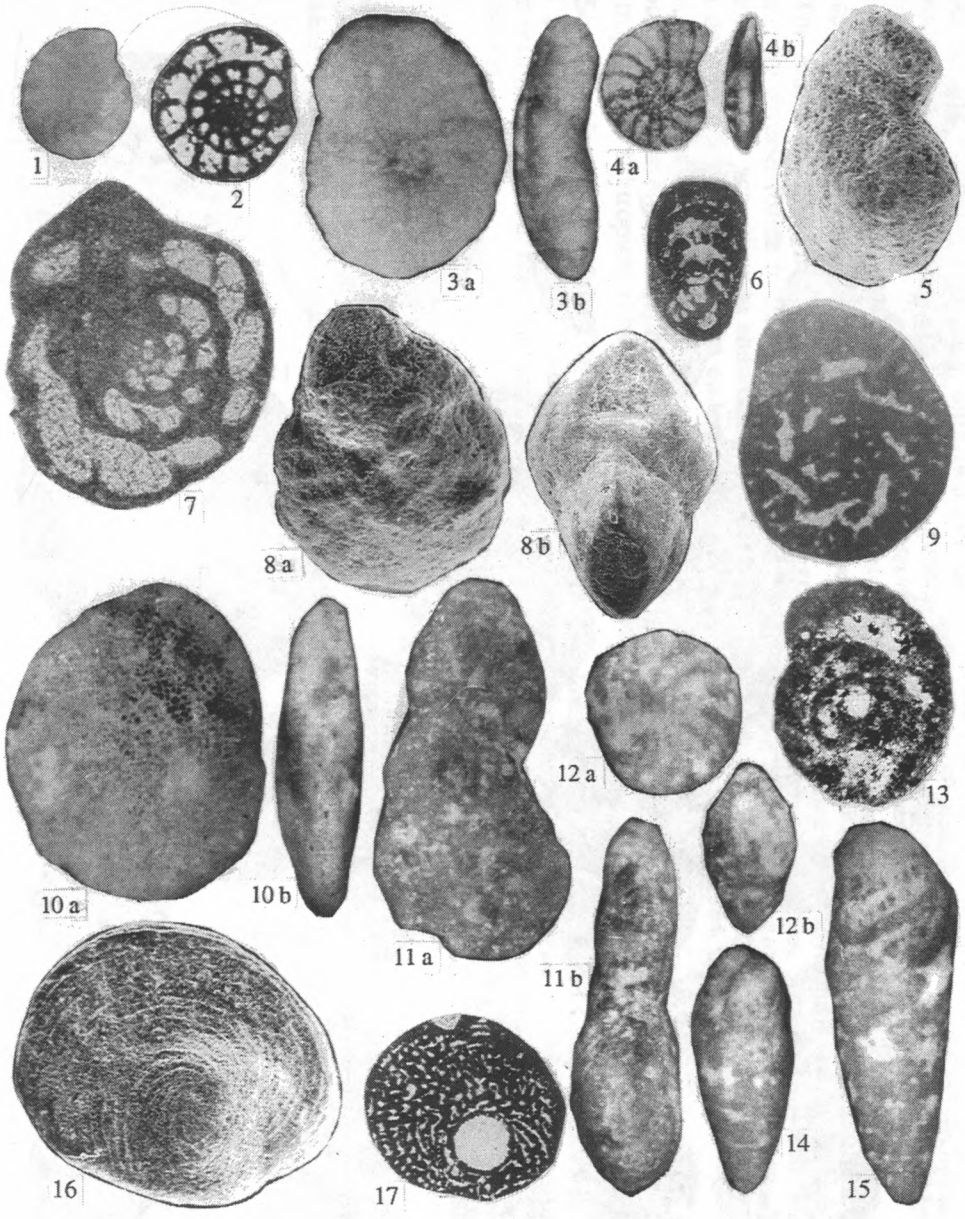

Plate I. Tithonian foraminifers of the Crimea and Syria.

1, 2 – *Nautiloculina oolithica* Mohler: 1 – specimen 4656/254, Geological Institute, Russian Academy of Sciences, lateral side, Syria, mountains of Anti-Lebanon, Wadi–Al-Karn section, the Tithonian, magnification ×50 and 2 – specimen 4656/255, Geological Institute, Russian Academy of Sciences, equatorial section, the same locality and age, magnification ×75; 3 – *Phenacophragma* sp. Specimen 4656/256, Geological Institute, Russian Academy of Sciences, a – lateral side, b – peripheral edge, Syria, mountains of Anti-Lebanon, Sad–Al-Karn section, Tithonian, magnification ×50; 4 – *Stomatostoecha compressa* Gorbatchik. Specimen 83-159, Moscow State University, a – lateral side, b – peripheral edge, the Crimea, the Tonas River section, Lower Berriasian, magnification ×75; 5 – *Charentia evoluta* (Gorbatchik). Specimen 261-23, Moscow State University, lateral side, the Crimea, the Dolgorukov Yaila, Lower Berriasian, magnification ×51; 6 – *Bramkampella arabica* Redmond. Specimen 261-167, Moscow State University, axial section, the Crimea, Ai-Petri, Upper Tithonian–Lower Berriasian, magnification ×30; 7, 8 – *Melathrokerion spirialis* Gorbatchik: 7 – specimen 261-157, Moscow State University, equatorial section, the Crimea, the Peredovoe Village region, Lower Berriasian, magnification ×90, 8a – specimen 261-211, Moscow State University, lateral side, and 8b – specimen 261-21, Moscow State University, peripheral edge, magnification ×130, the Crimea, Ai-Petri, Lower Berriasian; 9 – *Pseudocyclammina sphaeroidalis* Hottinger, specimen 261-167, Moscow State University, equatorial section, the Crimea, the Karabi Yaila, Upper Tithonian, magnification ×30; 10 – *Choffatella decipiens* Schlumberger. Specimen 4656/261, Geological Institute, Russian Academy of Sciences, a – lateral side, b – peripheral edge, Syria, mountains of Anti-Lebanon, the Sad–Al-Karn section, Tithonian, magnification ×50; 11 – *Everticyclammina* aff. *greigi* (Henson). Specimen 4656/260, Geological Institute, Russian Academy of Sciences, a – lateral side, b – peripheral edge, Syria, mountains of Anti-Lebanon, Rowda, Tithonian, magnification ×50; 12, 13 – *Alveosepta powersi* (Redmond): 12 – specimen 4656/258, Geological Institute, Russian Academy of Sciences, a – lateral side, b – peripheral edge, Syria, mountains of Anti-Lebanon, the Wadi–Al-Karn section, Tithonian, magnification ×50 and 13 – specimen 4656/259, Geological Institute, Russian Academy of Sciences, equatorial section, the same locality and age, magnification ×75; 14, 15 – *Kurnubia jurassica* Redmond: 14 – specimen 4656/256, Geological Institute, Russian Academy of Sciences, lateral side, young individual, Syria, mountains of Anti-Lebanon, the Wadi–Al-Karn section, Tithonian, magnification ×50 and 15 – specimen 4656/257, Geological Institute, Russian Academy of Sciences, lateral side, the same locality and age, magnification ×50; 16, 17 – *Anchispirocyclina lusitanica* (Egger): 16 – specimen 261-56, Moscow State University, lateral side, the Crimea, Ai-Petri, Upper Tithonian–Lower Berriasian, magnification ×20 and 17 – specimen 261-190, Moscow State University, equatorial section, the Crimea, Ai-Petri, Upper Tithonian–Lower Berriasian, magnification ×30.

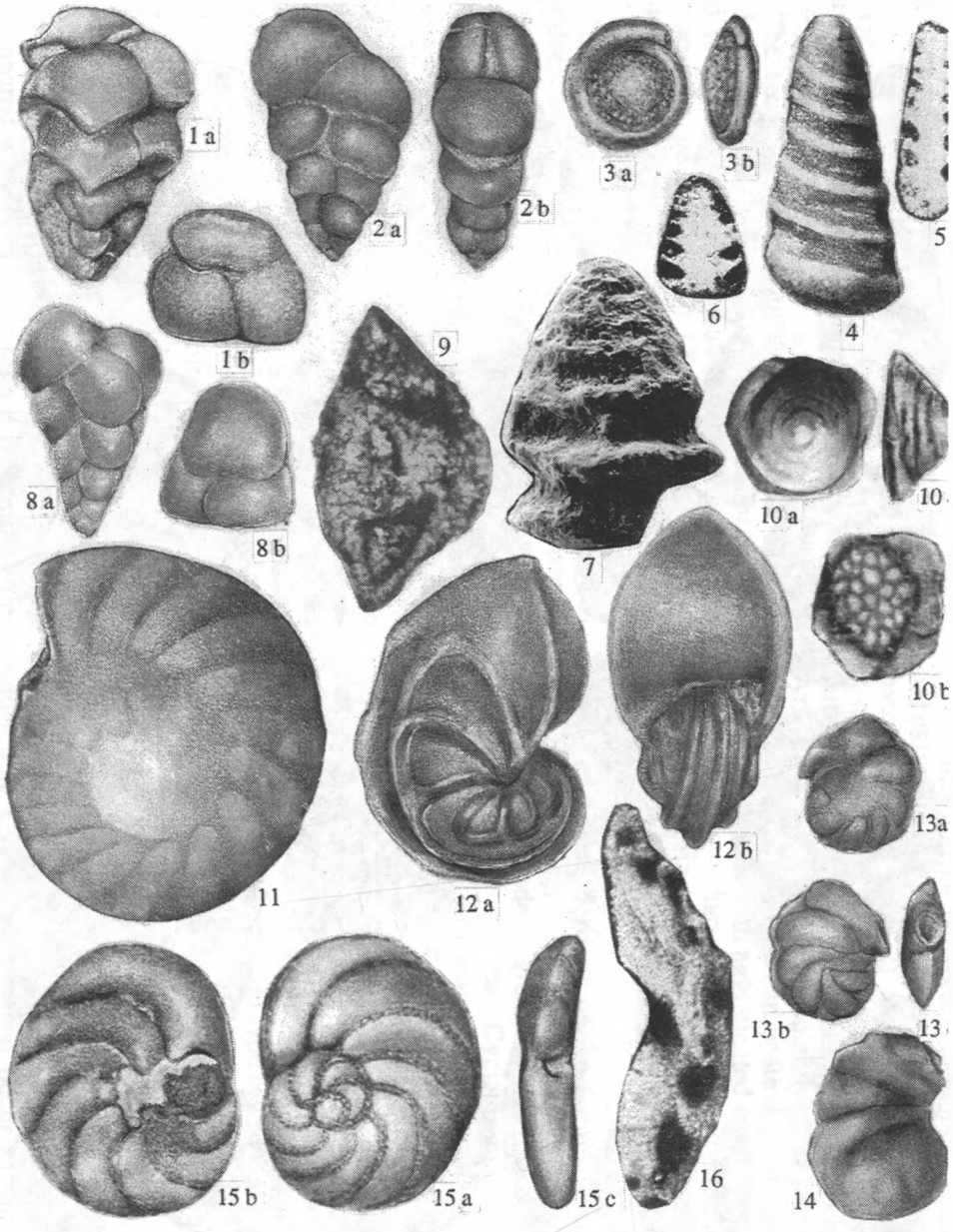

Plate II. Berriasian foraminifers of the Crimea and Syria.

1 – *Verneuilina angularis* Gorbatchik. Holotype 83/178, Moscow State University, a – lateral side, b – as viewed from aperture, the Crimea, the Tonas River, Lower Berriasian, magnification ×80; 2 – *Belorussiella taurica* Gorbatchik. Specimen 261-227, Moscow State University, a – lateral side, b – as viewed from aperture, the Crimea, the Tonas River, Lower Berriasian, magnification ×80; 3 – *Globospirillina caucasica* (Hoffman). Specimen 227/69, Moscow State University, a – lateral side, b – peripheral edge, the Crimea, the Tonas River, Lower Berriasian, magnification ×80; 4, 5 – *Trocholina elongata* (Leupold): 4 – specimen 227/75, Moscow State University, lateral side, the Crimea, the Tonas River, Lower Berriasian, magnification ×50 and 5 – specimen 261-205, Moscow State University, axial section, the Crimea, the Karabi Yaila, Lower Berriasian, magnification ×20; 6 – *Trocholina alpina* (Leupold). Specimen 261-206, Moscow State University, axial section, the Crimea, the Peredovoe Village region, Lower Berriasian, magnification ×30; 7 – *Trocholina companella* Arnaud. Specimen 261-144, Moscow State University, lateral side, the Crimea, the Karabi Yaila, Lower Berriasian, magnification ×53; 8 – *Verneuilina subminuta* Gorbatchik. Specimen 83/177, Moscow State University, a – lateral side, b – as viewed from aperture, the Crimea, the Sarysu River, Lower Berriasian, magnification ×80; 9 – *Protopeneroplis ultragranulatus* (Gorbatchik). Specimen 261-125, Moscow State University, axial section, the Crimea, the Tonas River, Lower Berriasian, magnification ×100; 10 – *Trocholina molesta* Gorbatchik. Specimen 83-302, Moscow State University, a – spiral side, b – umbilical side, c – peripheral edge, the Crimea, the Tonas River, Lower Berriasian, magnification ×75; 11 – *Lenticulina macra* Gorbatchik. Specimen 227/47, Moscow State University, lateral side, the Crimea, the Bel'bek River, Upper Berriasian, magnification ×80; 12 – *Lenticulina protodecimae* Dieni et Massari. Specimen 83-220, Moscow State University, a – lateral side, b – peripheral edge, the Crimea, the Burul'cha River, Berriasian, magnification ×75; 13, 14 – *Pseudosiphininella antiqua* (Gorbatchik): 13 – specimen 83-272, Moscow State University, a – spiral side, b – umbilical side, c – peripheral edge, the Crimea, the Tonas River, Berriasian, magnification ×80 and 14 – specimen 83-271, Moscow State University, umbilical side, the Crimea, the Michurinskoe Village region, magnification ×80; 15, 16 – *Discorbis crimicus* Schokina: 15 – specimen 83-255, Moscow State University, a – spiral side, b – umbilical side, c – peripheral edge, the Crimea, the Tonas River, Lower Berriasian, magnification ×80 and 16 – specimen 261-226, Moscow State University, axial section, the Crimea, Ai-Petri, Upper Tithonian–Lower Berriasian, magnification ×90.

zone. These sediments yielded a very peculiar assemblage containing various forms: Nodosariidae, Lenticulinidae, Vaginulinidae, Epistominidae, Involutinidae, and others. Most of the genera have a broad distribution. They are recorded outside the Tethyan realm, in the boreal water areas, where they are present as strong dominants in the assemblages. Therefore, the deeper water assemblages are known as boreal-cosmopolitan. Pyatkova reported assemblages of similar species and generic composition from the Tithonian sediments of the Crimean continental slope of the Black Sea (*Mezozoiskie Otlozheniya* ..., 1989).

The Tithonian deposits of Syria contain assemblages of mixed composition, including the Tethyan and Subtethyan forms. No boreal-cosmopolitan assemblages with Nodosariidae, Lenticulinidae, and Epistominidae, which are typical of the lower sublittoral zone, have been found there (Fig. 2). These forms are represented by rare tests of a few species (Table 3).

The above data suggests the following conclusions. The foraminiferal species, which are not restricted to the narrow stratigraphic interval, predominate in the Tithonian of both the Crimea and Syria. Most of these species (75%) pass from the Kimmeridgian into the Tithonian or, having appeared in the Late Tithonian, they evolve in the Berriasian.

As for the Tithonian endemics, only two families (Pfenderinidae and Nautiloculinidae) and five genera (*Kurnubia*, *Nautiloculina*, *Torinosuella*, *Choffatella*, and *Alveosepta*) are tropical Tethyan endemics, which are spread throughout Syria but missing in the Crimea.

The boreal-cosmopolitan forms are the most taxonomically diverse forms in the Tithonian of the both regions, whereas according to abundance, i.e., population density, the tropical Tethyan endemics are dominant, e.g., *Kurnubia jurassica* in Syria and subtropical Subtethyan forms, e.g., *Anchispirocyclina lusitanica*, in the tropical and subtropical zones of the Crimea.

Some species typical of the Tithonian of the Crimea and Syria are represented in Plates I and II. Their descriptions are given in literature and, therefore, omitted herein.

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Flora at the Cretaceous–Paleogene Boundary in Northeastern Russia

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Abstract – The floral succession in the Maestrichtian–Danian was studied on the basis of the distribution of 86 species from 124 sites in a continuous sequence of the Rarytkin Formation in the Koryak Highland. The succession of the Rarytkin Formation floral assemblages was divided into two stages: the Gornorechenskii (the Middle Maestrichtian) and the Rarytkin (the Late Maestrichtian–Danian). The most significant changes in flora occurred not at the Cretaceous–Paleogene boundary, but somewhat earlier, in the Late Maestrichtian. An analysis of the taxonomy and leaf morphology showed that the climate during the Rarytkin time was colder and more humid than in the Gornorechenskii time. The study of the ecological and taxonomical regularities of the flora change near the Cretaceous–Paleogene boundary in the Koryak Highland and the nonsynchronous replacement of the Maestrichtian-type flora by the Danian-type at different latitudes suggests that this replacement resulted from natural evolutionary processes and climate cooling rather than from some catastrophic extraterrestrial phenomenon.

One of the most interesting problems in the study of the Earth's past is the problem of the formation and transformation of ecosystems accompanied by major biota changes in the course of various ecological crises. Mankind is already convinced that this is the most influential factor with respect to environmental changes on a global scale. However, nobody can foresee and assess the consequences of this interference in the future. Nowadays, natural ecosystems are destroyed in vast areas, the structure of surviving communities is disturbed, and a persistent decrease in the life diversity in its entirety can be observed. However, nature does not tolerate vacuums, and new types of communities should form in place of those destroyed by humanity, i.e., forests, steppes, and other ecosystems. In principle, this process has already begun. There are fauna, vegetation, and communities that can be called anthropogenic. However, most of them have a pioneer character, being at a merely initial stage, and their study cannot answer all the questions concerning the consequences of such changes. Is it worth our effort to protect that which remains of the existing nature, or it would be better to objectively influence the formation of new communities? This is one of the principal questions, and to answer it, it is necessary to know the mechanisms and regularities of major biota changes, that repeatedly occurred on the Earth. In other words, to study the changes of fossil floras and faunas under different climatic conditions and under the influence of different catastrophic factors.

Up to now, the study of the diversity evolution in the past was carried out mainly by means of calculating the changing number of taxa in various taxonomic groups within the major units of a geochronological scale. Applying such a technique, the organisms, originating from different ecosystems and natural zones, are usually counted, but this does allow us to estimate the events ecologically and creates an impression of a simultaneous and global extinction of various organisms. Such an impression existed with respect to the Cretaceous–Paleogene boundary.

At present most authors consider the changes at the Cretaceous–Paleogene boundary to be evolutionary rather than catastrophic. However the concept of global catastrophe at the end of the Cretaceous became very widespread. A striking instance of this is the popular hypothesis of Alvarez *et al.*, (1980) in which the events at the Cretaceous–Paleogene boundary are explained by the fall of a large meteorite.

A more objective study of ecological crises requires the analysis of changes of certain floras and faunas within a single geographical region, best of all, in a single section, taking into account the change in paleogeographic and paleoclimatic environments. As fauna and flora are the most significant part of terrestrial ecosystems and sensitive indicators of the ecosystem's state, analysis of their changes during an ecological crisis is particularly significant for understanding the regularities of biota evolution.

Within the Koryak Highland (northeastern Russia), marine and continental deposits of Maestrichtian and Danian ages are widely distributed. They consist of continuous sections, embracing the Cretaceous–Paleogene boundary beds. One of the most complete continental sections, containing abundant floral remains, is the section of the Rarytkin Formation in the Gornaya River basin (northeastern Rarytkin Ridge). The Rarytkin Formation consists of lacustrine, palustrine, allu-

vial, and deltaic deposits of an extensive coastal lowland, being composed of cyclically alternating sandstones, siltstones, and coals, about 2000 m thick. In order to study flora evolution at the Cretaceous–Paleogene boundary, 86 species from 124 sites along the section were examined and a number of floral assemblages, superseding one another in time, were identified. The general diversity of species within each assemblage and the number of extinct, newly appeared, and transit ones were calculated, and the abundance of species was assessed according to a three-mark scale. Analysis of diversity change within different ecological groups and the study of the behaviour of dominant species made it possible to infer the definite mechanisms of replacements of the Maestrichtian flora by the Danian one within the Koryak Highland.

The flora from the Rarytkin Formation can be divided into two floral assemblages: the Gornorechenskii (the Middle Maestrichtian) and the Rarytkin (the Late Maestrichtian–Danian), each of them consists of two subassemblages (the table). The age of these assemblages and subassemblages was defined by correlating them with other floral units from the Maestrichtian–Danian sequences of the Koryak Highland, including alternating marine and continental deposits with both florae and faunal remains (Nesov and Golovneva, 1990).

Characteristic of the Gornorechenskii floral assemblage is the predominance of angiosperms, and among them the *Peculnea*, *Trochodendroides*, *Celastrinites*, *Renea*, *Dyrana*, *Platanus*, *Viburnum*, *Quereuxia*, *Palaeotrapa*, and *Corylus* genera. Conifers are not numerous and predominantly consist of typical Late Cretaceous taxa: *Sequoia minuta* Sveschn., *Cryptomerites*, and *Taxites* with an admixture of younger *Metasequoia* and *Glyptostrobus*. Rather abundant are *Ginkgo* and cycadophytes (*Nilssonia*), forming, apparently, monodominant communities. Ferns are represented by solitary finds of *Osmunda*.

In the Rarytkin floral assemblage, conifers are no less abundant than angiosperms. *Croylus*, several species of *Trochodendroides*, *Metasequoia*, *Glyptostrobus*, and *Microconium* dominate the flora. Also typical are *Taxodium*, *Platanus raynoldsii* Newb., *Quercus groenlandica* Heer, *Arthollia*, *Rarytkinia*, *Celastrinites*, *Nyssa*, *Platimelis*, *Viburnum*, *Vitis*, *Quereuxia*, and *Haemanthophyllum*. The *Ginkgo* remains are rarely present, and cycadophytes are absent. Ferns (*Onoclea* and *Coniopteris*) are present more frequently than in the Gornorechenskii assemblage. The specific composition and the dominants change considerably at the boundary between the Gornorechenskii and Rarytkin assemblages in all the plant groups. These assemblages correspond to two evolutionary stages of the Beringian paleoflora, which can be traced regionally and received the same names as the assemblages (Golovneva, 1991).

Analysis of flora evolution in the Late Cretaceous of northeastern Russia, from the Penzhina (Herman, 1988) to the Gornorechenskii stage shows that angiosperms evolved intensely during this time. From 60 to 80% of their composition was constantly renewed with each subsequent stage. Conifers, on the contrary, changed little during the Late Cretaceous and consisted virtually of the same genera and even species in different floras. Perhaps further investigations, using a cuticular and epidermal analysis, will show that the composition of Late Cretaceous conifers was not so monotonous as was inferred from a morphological analysis of sprouts. But, nevertheless, many taxa seem to have a considerable vertical range. The share of relict elements (ginkgoales, cycadophytes, and ferns) in the Late Cretaceous floras gradually decreased. The Gornorechenskii stage was the last in which typical Late Cretaceous conifers were fairly abundant. The present-day coniferous genera, which were characteristic components of Tertiary floras, already dominated at the Rarytkin stage. The last cycadophytes disappeared at the Gornorechenskii–Rarytkin boundary. *Ginkgo* lost its dominant role and was found in later floras only as a subordinate component. Thus, a substantial change in the gymnosperm composition occurred at this boundary: typically Late Cretaceous dominants were replaced by Paleogene ones, and the last relics of the Mesophytic disappeared. As for the angiosperms, the degree of their taxa renewal at this boundary was not greater than at the previous Late Cretaceous stages in northeastern Russia. More considerable changes in their evolution occurred later on, in the Late Paleocene, when its rate became faster and the main role in the floras was played by the representatives of present-day genera from the Ulmaceae, Betulaceae, Juglandaceae, Fagaceae, and Platanaceae families (the Napan stage according to Budantsev, 1983).

Floral assemblages of the Rarytkin Formation and their age

Stratigraphic units	Rarytkin Formation			
	lower subformation	middle subformation		upper subformation
Floral assemblages	Gornorechenskii		Rarytkin	
	Early	Late	Early	Late
Age	Maestrichtian			Danian
	Middle		Late	

Sixteen species are common to the Gornorechenskii and Rarytkin assemblages (Fig. 1). These are mainly the most characteristic representatives of the Rarytkin assemblage, which first appeared in the Gornorechenskii assemblage and became dominant after the boundary between these stages. The most typical representatives of the Gornorechenskii assemblage sharply disappeared at the boundary and did not spread into the overlying deposits. No changes in dominants occurred at the boundary between the Early and Late Rarytkin subassemblages; the changes in composition and occurrence frequency occurred among the minor species.

In order to assess paleoclimatic changes, the taxonomy of floral assemblages and leaf morphology were analyzed (Wolfe, 1969, 1971; Dilcher, 1973; Krasilov,

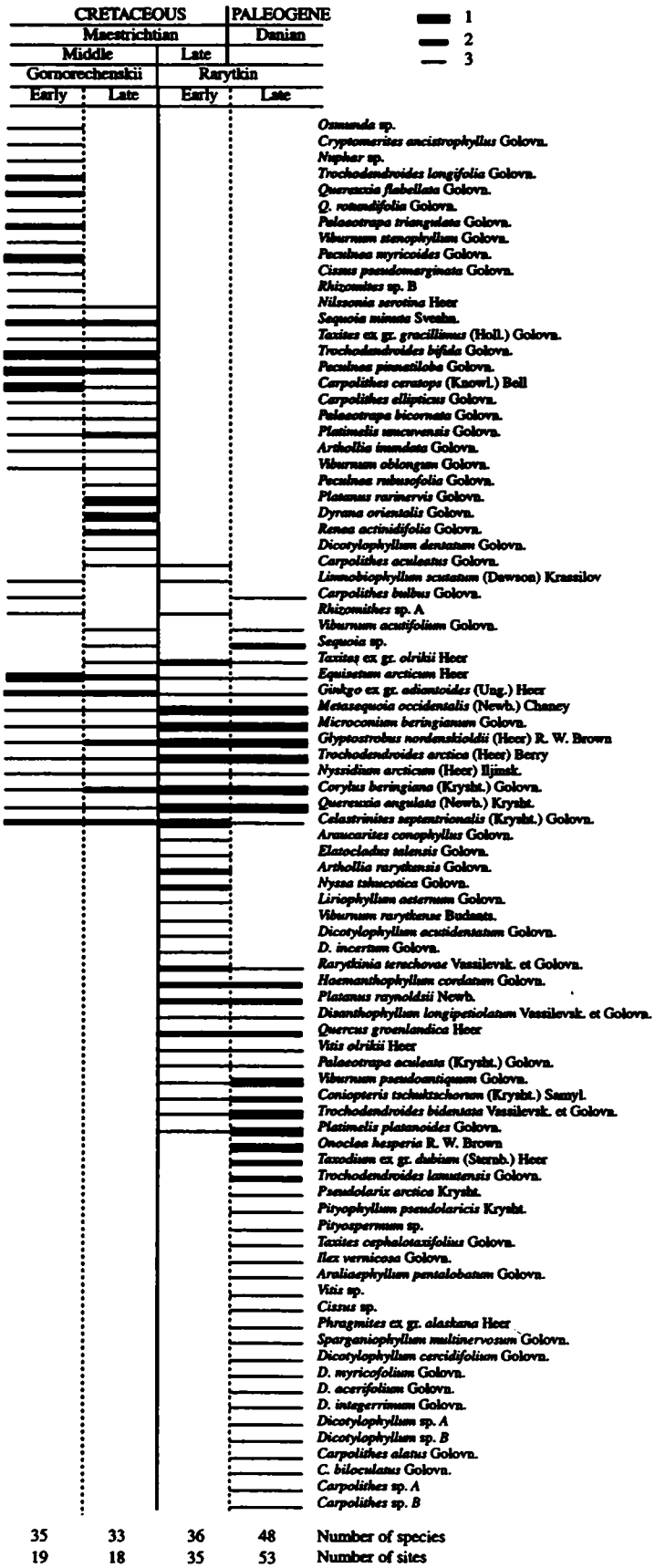

Fig. 1. Distribution of the Rarytkin flora species in the floral assemblages and their degree of dominance.

1 – dominants; 2 – characteristic species; 3 – rare species.

1979). The transition from the Gornorechenskii assemblage to the Rarytkin was accompanied by the following:

(1) an increase in the angiosperm leaf size and in the abundance of conifers, ferns, and platan-like plants;

(2) a decrease in the relative abundance of angiosperms with thick, entire leaves; and

(3) a disappearance of evergreen conifers and cycadophytes. These facts indicate a colder and more humid climate during the Rarytkin stage than in the Gornorechenskii. The increased number and thickness of coal interbeds in the upper part of the Rarytkin Formation confirms the increase in climate humidity.

The Gornorechenskii floral assemblage differs considerably from the synchronous floras of Sakhalin (Krasilov, 1979) and Canada (Berry, 1935; Bell, 1949; Rouse, 1967) at the generic and specific levels. Evidently, the floras of these regions evolved in the Maestrichtian independently. The Rarytkin assemblage, on the contrary, consists mainly of species of a wide geographical distribution and resembles many Danian-type floras of the Northern Hemisphere: the Boshnyakovo from Sakhalin (Krasilov, 1979), the Tsagayan from the Amur region (Krasilov, 1977), and the Early Paleocene floras from Canada (Berry, 1935; Bell, 1949) and Spitsbergen (Budantsev, 1983). The cores of all these floras were formed by the species and genera of almost circum-Polar distribution areas. Due to cooling during the Late Maestrichtian–Danian, the boundary of the northern temperate zone shifted southward, which was conducive to an increase of these distribution areas. The wide migration of floras in this time was facilitated, too, by an extensive regression, resulting in the broadening of land bridges in various regions (Naidin *et al.*, 1986). Thus, in the Latest Maestrichtian–Danian a rather monotonous temperate flora developed within the Boreal–Pacific subregion (Budantsev, 1983). The provincial differences between the floras of northeastern Russia, Canada, and Sakhalin, which was observed in the Maestrichtian, disappeared almost completely.

It should be emphasized that the Maestrichtian-type flora (Gornorechenskii assemblage)was replaced by the Danian-type flora (Rarytkin assemblage) within the Koryak Highland somewhat earlier than the Cretaceous–Paleogene boundary, probably at the boundary between the Middle and Late Maestrichtian (Nesov and Golovneva, 1990), during cooling at high latitudes of the Northern Hemisphere (Kaufmann, 1984; Zakharov *et al.*, 1984). Earlier and more considerable cooling at high latitudes, in comparison with low latitudes, resulted, probably, from the increase of a latitudinal thermal gradient during the Late Cretaceous–Paleogene (Hickey, 1981). The Maestrichtian–Danian boundary is situated inside the Rarytkin stage of flora evolution and corresponds, probably, to the events at the boundary between the Early and Late Rarytkin subassemblages (the table). It follows from all this that the transition from the Maestrichtian-type flora to the Danian-type at different latitudes was not simultaneous. This fact contradicts various theories suggesting a catastrophic change of biota at the Cretaceous–Paleogene boundary. It can be suggested that the Danian-type flora was formed at high latitudes during the Late Maestrichtian and spread gradually southward in accordance with progressive cooling.

Analysis of diversity change showed that the Rarytkin assemblage species diversity was approximately 27% greater than that of the Gornorechenskii assemblage (Fig. 2). General diversity of the Late Rarytkin subassemblage was 37% greater than that of the Early Rarytkin, but many Late Rarytkin new species were rare ones. This contradicts the data of many palynologists, who noted the decrease in the Danian flora diversity in comparison with that of the Maestrichtian (Hickey, 1981; Jerzykiewicz and Sweet, 1986; Spicer, 1989). The analysis of species extinction shows that almost the same number of species disappears in each subassemblage, while the number of newly appearing species increases in each subassemblage. On the whole, 70% of the Rarytkin assemblage consists of new species, and thus flora change at the boundary between the Gornorechenskii and Rarytkin stages was determined by the appearance of new species rather than by extinction.

In all, 60% of the species became extinct at this boundary. It is quite comparable with the extinction rate in other Late Cretaceous floras of northeastern Asia, which is usually 50 - 80%. For instance, in northwestern Kamchatka four floral assemblages successively replaced one another from the Turonian to Santonian: the Penzhina, Kaivayam, Valizhgen, and Upper Bystraya (Herman, 1988). The flora here evolved during gradual warming and aridization of the climate. Each change of floral assemblages resulted in 60 - 80% of all the species becoming extinct. In Sakhalin, five floral assemblages were identified from the Coniacian to Danian: the Ainu, Gilyak, Zhonk'er, Avgustovka, and Boshnyakovo (Krasilov, 1979). In this succession, the degree of extinction at the transition from one assemblage to another was 50 - 60% and at the transition to the Danian assemblage, 75%. The Danian Boshnyakovo flora, like the Rarytkin flora,

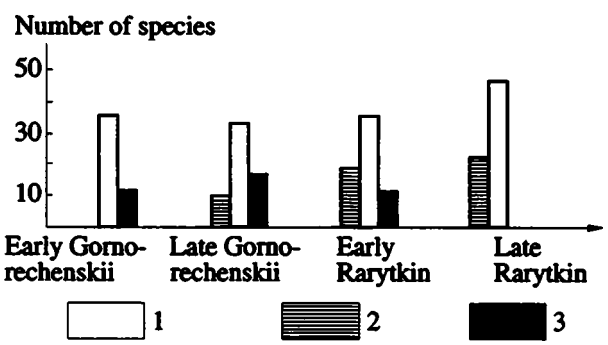

Fig. 2. Change in species diversity in floral subassemblages from the Rarytkin Formation.

1 – total number of species; 2 – number of species appearing in the subassemblage in comparison with the previous one; 3 – number of species disappearing in the subassemblage in comparison with the previous one.

contains a great amount of new species: 80% in comparison with 20 - 50% in previous assemblages.

Changes in community structures occurred at the transition from the Gornorechenskii stage to the Rarytkin. Most Gornorechenskii communities were most likely polydominant. The remains of any single species never predominate others, with the exception of ginkgo and cycadophytes, whose remains may form monodominant "leaf roofs." Characteristic of the Rarytkin assemblage, despite its general diversity increase, was a more strongly pronounced degree of dominance. In most sites, 4 - 5 species dominate, with their remains amounting for 70 - 90% of the total number of the finds. Besides the dominants, the flora contained a group of characteristic species, which occurred rather frequently, though small in number. Other species were present rarely. These facts indicate that community structures became simpler during the Rarytkin time, which was, most probably, related to climate cooling.

Many dominants of the Rarytkin flora are present in almost all the sites, independent of sedimentary facies. Most of them are widely distributed geographically and have a considerable stratigraphic range (transit species). Thus, the Rarytkin flora dominants were of a wide ecological range, i.e., were eurybiontic. Almost all the plants of the Rarytkin assemblage had a very high individual variability among their leaves, which usually indicates the absence of narrow specialization. It is known that the predominance of widely distributed eurybiontic species of a high individual variability is characteristic of communities under strong pressure from the surrounding environment and taxonomically impoverished. The same structure is characteristic of some pioneer and anthropogenic communities (Vakhrushev, 1984). A similar situation arose in the Late Maestrichtian as a result of the extinction of specialized Cretaceous stenobiontic species and the cooling that secured the dominance of eurybiontic species and their wide distribution. With the removal of outward pressure (for instance, with the change in cooling by warming), a rapid radiation and species specialization should begin in such taxonomically impoverished open communities (Nesov and Golovneva, 1987). Evidently, such processes occurred only in the floras of the Latest Paleocene to the Earliest Eocene.

The regularities in flora change near the Cretaceous–Paleogene boundary suggest that this change resulted from natural evolutionary processes and climate cooling rather than from some catastrophic event of an extraterrestrial origin. It is confirmed by the following:

(1) a nonsynchronous replacement of the Maestrichtian-type flora by the Danian-type flora at different latitudes;

(2) a continuity in the evolution of the Maestrichtian and Danian floras: many characteristic species of the Danian flora still appeared in Gornorechenskii time and gradually became more abundant upsection;

(3) the extinction degree near the Cretaceous–Paleogene boundary did not exceed that of other changes in flora during the Late Cretaceous in Northeast Asia;

(4) the floral change at the boundary between the Gornorechenskii and Rarytkin stages resulted more from the appearance of new species than from the extinction of old ones.

Many paleobotanists and palynologists support the idea of evolutionary transformation of the flora at the Cretaceous–Paleogene boundary (Shoemaker, 1966; Srivastava, 1970; Vakhrameev and Akhmet'ev, 1977; Zaklinskaya, 1977; Krasilov, 1976, 1979, 1989; Hickey, 1980, 1984; Spicer, 1989). However, the catastrophic meteorite theory also has at present many proponents (Tschudy *et al.*, 1984; Tschudy and Tschudy, 1986; Wolfe and Upchurch, 1986, 1987; Saito *et al.*, 1986; Lerbekmo *et al.*, 1987; Johnson *et al.*, 1989 and others). This theory is supported by a widespread coincidence of sharp changes in the palynocomplexes, corresponding to the Cretaceous–Paleogene boundary, with the iridium anomaly. More detailed palynological investigations revealed that in many sections a "fern peak" is confined to this boundary as well. This phenomenon is manifested in a sharp decrease in the diversity of all taxa and an increase in the abundance of fern spores at a few centimeters in the section immediately above the iridium anomaly. The specific diversity is then gradually renewed. This change was most thoroughly analyzed with reference to leaf floras and palynocomplexes in the Raton basin, United States (Wolfe and Upchurch, 1987), but a similar scenario can be observed in other sections as well (Wolfe and Upchurch, 1986; Lerbekmo *et al.*, 1987). Sometimes an increase in the abundance of 1 - 2 species of phanerogams can be observed instead of the "fern peak" (Jerzykiewicz and Sweet, 1986). These facts were interpreted to be a recolonization of an area devastated by a meteorite impact, which had been following normal succession processes. Ferns and herbaceous phanerogams were considered to be the first pioneer groups.

Quantitative estimates of species extinction at the Cretaceous–Paleogene boundary, given in different publications, are quite different, and it is difficult to compare them. Often the same figures are interpreted either as a catastrophic or as a gradual extinction, depending on the authors' theoretical views.

Indications of cooling near the Maestrichtian–Danian boundary were noted in most publications by American authors both in leaf floras and in palynocomplexes. In northern regions (Canada), the increase in the abundance of fern spores and coniferous pollen, the predominance of conifers over phanerogams, and the replacement of evergreen conifers by deciduous ones were recorded (Srivastava, 1970; Nichols *et al.*, 1986; Jerzykiewicz and Sweet, 1986; Lerbekmo *et al.*, 1987). Characteristic of the southern regions of the Cretaceous tropical and subtropical zones were the primary extinction of evergreen phanerogams as compared with deciduous ones and the migration of temperate elements from the north (Wolfe and Upchurch, 1986; Spicer, 1989). Supporters of the meteorite theory regard these changes as the result of a sudden, short-term cooling, which follows the "nuclear winter" model, rather than the result

of a usual change in climate. However, climatic changes near the Cretaceous–Paleogene boundary in different geographical regions were not the same at all and thus cannot be explained by a single catastrophic extraterrestrial event. For instance, the cooling in northeastern Russia began in the Late Maestrichtian, and in Canada at the Maestrichtian–Danian boundary. Johnson *et al.* (1989) noted climate warming in the Late Maestrichtian in the northwestern United States, which preceded the cooling at the Cretaceous–Paleogene boundary, while an increase in climate humidity without temperature changes was recorded in the Raton basin (Wolfe and Upchurch, 1987).

Some geographical regularities in flora change at the Cretaceous–Paleogene boundary also attract attention (Shoemaker, 1966; Wolfe and Upchurch, 1986; Spicer, 1989). In the southern regions of North America the extinction degree was higher than in the northern regions, mainly at the expense of the disappearance of evergreen species. At high latitudes of the Northern Hemisphere, Danian floral elements had already appeared in the Maestrichtian, whereas at the middle latitudes (south of Montana) it occurred only at the Maestrichtian–Danian boundary (Shoemaker, 1966). A considerably larger amount of Mesozoic relics in the Danian floras survived in the southern regions of North America than in the northern regions (Tschudy and Tschudy, 1986). Flora change at the Cretaceous–Paleogene boundary in temperate and tropical zones of the Southern Hemisphere was inconsiderable in comparison with that in the Northern Hemisphere (Tschudy, 1984; Spicer, 1989).

This writer's investigations and published data suggest that a Danian-type flora began formation at high latitudes as early as in the Maestrichtian and gradually migrated southward with the onset of the cooling. Therefore, the changes in the specific composition of northern floras were not too sharp, being manifested mainly in the change of the dominants. At middle latitudes the flora changed mainly as a result of migration processes rather than evolutionary ones, and, therefore, the changes within floral assemblages in sections look more sharp and sudden. Krasilov (1979, 1989) relates the change in floral assemblages in the Maestrichtian-Danian sections to latitudinal vegetation belts shifting southward as a result of climate cooling. In this case, the sharpness of the change was caused more by species migration than direct extinction and a rise in taxonomic groups.

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Some Problems Concerning the Geological History of the Caspian Sea

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Abstract – Some problems concerning the geological history of the Caspian Sea as a lacustrine basin in Late Pliocene (Akchagylian) and Pleistocene are considered. The possibility of a significant increase in salinity in the Balakhanian basin is pointed out. The basin is assumed to be a refuge for the Sarmatian and Pontian relicts of the Akchagylian fauna. Particular emphasis is placed upon transgressive and regressive cycles of the Caspian Sea during the Pleistocene as a basis for super long-term forecasts of its level changes.

The Caspian Sea, a giant lake, has a complex geological history. Its history can be followed from the end of Pontian, when the Sea was separated from the main basin of eastern Parathetys and turned into isolated continental water basin. One of the peculiar features of this unique sea were major transgressions and regressions that alternatively flooded or drained vast territories north of the Caspian Sea, in eastern Transcaucasia, and in the Transcaspian region.

The water mass distribution and basin boundaries were essentially controlled by tectonic movements that alternately submerged and uplifted various parts of the Caspian depression. As was noted by D.A. Tugolesov (1948) and recently demonstrated by M.L. Kopp and I.G. Shcherba (1992) these movements were, however, not a decisive factor in the change of water volume and therefore in sea level fluctuations.

A study of the Pleistocene history of the Caspian Sea demonstrated that marine transgression, regression cycles, were controlled by general and regional climatic changes and were functionally related to the water balance (Apollov, 1956; Fedorov, 1957; and others).

In spite of my long-standing studies of the Pleistocene history of the Ponto-Caspian basin I want to reconsider it once more. Particularly, the Caspian part, where many aspects of the geological record recently assumed a new significance. First of all, there are a number of topical problems related to frequent sea level changes and the necessity of their long-term forecast. The Pleistocene history of the sea and particularly its Late Khvalynian and Novocaspian intervals of less than 50 ka duration provide fairly convincing evidence that the climatic factor prevailed over others, like tectonics or an anthropogenous influence. In solving a number of paleogeographic problems, and first of all that of sea level fluctuations, we need a wide consideration of the basin's geological history. It started with the basins transformation into a lake in the Middle Pliocene, when the hydrological regime was dependent on the water balance of an extensive drainage area including rivers of western Central Asia, northern Iran, Caucasus, and the Russian plain.

I believe it necessary to use all the materials of my studies along the sea coasts regardless of modern state borders. Most importantly, I want to consider problems concerning the history of the Caspian.

It should be noted that the geological record of the Caspian Pliocene (particularly the Akchagylian) and Pleistocene (the Bakuvian and Khazarian) is still insufficiently studied. It requires further investigations not only ashore but in the shelf zone, and especially in its outer part.

At the end of the Pontian the Caspian depression was a brackish-water basin that lost later connections with the neighboring Kimmerian basin. Judging from paleogeography and geochemistry data, the regression of the Balakhan basin occured under arid climate conditions. Therefore, the Babadzhan brackish-water lake (terminal Pontian in the Caspian Sea), which was dramatically reduced in volume due to evaporation, should have experienced a salinity increase. This is indicated by gypsinated Balakhan red beds and by some paleontological data (Ali-Zade, 1961; Kolesnikov, 1950). Nonetheless, the concept of the fresh-water Balakhan basin is widespread in publications.

It seems highly unrealistic to infer a transformation of a brackish-water basin into a fresh-water one to be the result of evaporation and volume reduction. On the contrary, that basin would become a saline (if not a hypersaline) lake. As to the fresh-water mollusks in the Balakhan deposits, they have likely inhabited the river deltas of the lake, among them deltas of paleo-Amu-Dar'ya, paleo-Kura, and so on. Deposits of the Balakhan saline lake proper are apparently deeply buried (at a depth of several hundred meters), being still undetected by drilling.

The aforesaid allows us to consider the problem of the Akchagylian from the presently unpopular viewpoint of N.I. Andrusov (1923), which is so far the most realistic. The concept assumes that Akchagylian mac-

trid and cardiid ancestors, which originated at the Sarmatian (or Pontian), survived in some ecological niches of the Balakhan lake, and then gave rise to an explosive speciation at the end of the Balakhanian time, producing the Lower Akchagylian forms proper. It seems more natural, then, to consider the Ackchagylian fauna as an autochthonous one. The transgression itself can be regarded as a result of a considerable global humidity increase, which is the reason for a rise in the water volume of the Caspian Sea. In spite of A.A. Ali-Zade's intriguing hypothesis (1961) suggesting that the Aral–Karakum is a relict, I believe that the Caspian Sea or, to be more correct, the Balakhan basin was a refuge for the Sarmatian–Pontian fauna (Fedorov, 1959).

A short term connection with the Mediterranean Sea (most reliable from the viewpoint of paleogeography) and penetration of Akchagylian cardiid and mactrid ancestors from it to the Caspian Sea (by the way, from what particular basin of the Mediterranean?), as well as an ingress of a considerable volume of marine water into the "fresh-water" Balakhan basin past the Black Sea depression are not supported by any geological data or justified by reliable paleogeographic reconstructions. All these assumptions are purely theoretical and speculative. It should be remembered too that the Balakhanian Age, apart from the dramatic Caspian Sea regression, was marked by other significant geological events, like the formation of denudation relief in Transcaspian region, and the origin of deep drainage-free depressions such as the Karagie, Karabogaz, Karashor, Sarykamysh, and, partly, Aral. In recent years deep erosional incisions have been revealed by geophysical studies and drilling on slopes of the southern and Middle Caspian depressions (personal communication of P.N. Kuprin and A.E. Schlesinger). A considerable expansion of the Balakhan basin prior to the Akchagylian transgression proper was a result of intensive water inflow from the paleo-Volga, paleo-Kura, and paleo-Amu-Dar'ya during an increasing in climate humidity (the Kinel' Formation and its counterparts). These fluviatile and fluviolacustrine deposits of the Lower Akchagylian do not occur beyond the fresh-water basin areas, as in the Krasnovodsk Peninsula.

A transition from the Akchagylian to the Apsheronian basin was accompanied by a decrease in salinity and a general reduction of the basin area. Coastal, shallow zones were, once more after the Pontian, colonized exclusively by brackish-water mollusks. At first they retained morphological similarity and genetic affinity with some Akchagylian species, and later in the Late Apsheronian acquired a modern appearance. This is the level where the first ancestral forms of the Pleistocene Cardiidae and Dreissensiidae appeared.

Typical Pleistocene brackish-water malacofauna of true modern appearance originated in the Caspian Sea at the beginning of the Bakuvian time.

The Tyurkyanian marine regression[1] that took place after the Apsheronian transgression was an important event in the geological history of the sea and in the evolution of the brackish-water mollusk. From the viewpoint of historical geology and biostratigraphy, the boundary between the Apsheronian and Bakuvian, more precisely located at the base of the Tyurkyany Formation, is the most important stratigraphic level dividing the Pliocene and Pleistocene in the Ponto-Caspian region.

The Tyurkyanian regression with a sea-level decrease of 100 - 200 m and more (?) was followed by a prolonged and extensive Early Bakuvian transgression. It flooded the Kura lowland up to the Duzdag and Karadzha ranges, western Turkmenian lowland, the northern margin of the Caspian Sea, the area of eastern Manych and the Manych depression. The latter conducted one way water drainage into the Azov depression. The same drainage existed in the Akchagylian and Apsheronian. It was undoubtedly caused by a higher water level in the Caspian Sea, as compared to the Euxinian basin.

A similiar water exchange appeared each time during the Caspian transgressions in humid periods.

A special investigation (Fedorov, 1988) revealed that transgressions in the Caspian Sea and Caspian-type brackish-water events in the Black Sea were coeval and comparable in their levels, though in the first basin the level was slightly higher. Interglacial (Mediterranean) transgressions in the Black Sea took place immediately after the Caspian phases. They both form transgressive pairs that apparently correspond to beginning and optimum global warmings (interglaciations).

The Bakuvian deposits, which comprise a significant part of the Caspian Pleistocene sequence, were repeatedly described (Zhukov, 1945; Fedorov, 1953, 1957). I would like to call attention, however, to some of their essential features. A considerable thickness of the deposits (200 - 300 or even 500 m) clearly indicates a long sedimentation period. The composition of the Lower Bakuvian deposits is also peculiar. They are represented by stratified brown clays and silts with very thin interlayers of ocherous sands. Their fauna is poor and very uniform, consisting of *Didacna parvula* Nal. and more rare *D. catillus* Eichw. Both forms are typical of the entire basin from the Lower Volga region to southwest Turkmenia, and from northern Dagestan to the Kura lowland. This points to relatively uniform hydrological conditions of the long-lived basin.

The Upper Bakuvian deposits are represented by thin, coarse coastal facies produced as a result of coast abrasion in the course of further development of the transgression. They contain a rich assemblage of large massive cardiids *Didacna rudis* Nal., *D. carditoides*, and *D. eulachia* Bog. (Fed.), which are also typical of the entire Caspian basin. Deposits of the final stage of the Bakuvian sedimentation cycle, the Urundzhik

[1] After the village of Tyurkyanian in the south of the Apsheronian Peninsula.

sands, have a more restricted distribution. These sands and pebble gravels contain large and very characteristic *Didacna pravoslavlevi* Fed., *D. kolesnikovi* Fed., *D. mingetschaurica* Vekil., and *D. eulachia* Bog. (Fed.). *D.* ex. gr. *nalivkini* Wass., the typical form of the Khazarian, frequently occurs here too. Clearly within the entire Caspian basin these complexes are not uniform becase of variable ecological conditions. The index fossils mentioned here are, however universally represented in the Caspian Sea, Manych depression, and Kertch and Taman'peninsulas. Stratigraphic hiatuses between the Lower and the Upper Bakuvian as well as between the Upper Bakuvian and the Urundzhik are insignificant. Nevertheless, they are distinct and well justified by biostratigraphy and lithology in sections of the Apsheron Peninsula, western Turkmenia, and Buzachi Peninsula (margins of the Myastek and Kyzan depressions), as well as in drill sites all the along Caspian coasts.

This is why A.A. Svitoch's statement (1991), which suggested that the Caspian Lower Pleistocene cannot be subdivided, seems to be invalid. The same is true for his assertion about the Khazarian and the Khvalynian horizons. Besides, the relation of beds and their paleontological characteristics for the "Neftyanaya" ravine (Mishovdag) section are incorrectly interpreted in Svitoch's paper, which confused the stratigraphy of the Caspian Pleistocene. The best sequences of distinct Upper Bakuvian and Urundzhik beds with typical fauna and stratigraphic breaks are situated in the Balkhan lowland of western Turkmenia (Kumdag, Urundzhik), and in the Kura lowland (Mishovdag, Neftyanaya ravine). A terrace of the Urundzhik age is also on a slope of Malyi Kharami Range (Fedorov, 1957).

A graph of dynamic changes of the Caspian Sea level during the Early and Middle Pleistocene (Fig. 1) shows only the main trends of these processes. The graph is based on the maximum levels of transgressions, which are estimated in the framework of geological time taking into account tectonic dislocations. Regression minima are difficult to evaluate. The sea-level decrease up to tens and hundreds of meters may be suggested for regression periods, and general peculiarities of the transgressive-regressive cycles are fairly well inferred from geological data. The Tyurkyanian transgression was distinctly manifested in an over deepening of the Volga Valley (Goretskii, 1966) and other river valleys of the Caspian basin, and resulted in the deposition of the continental Tyurkyanian Formation, consisting of fluviatile and subaerial sediments. In western Turkmenia, the formation unconformably overlies the Apsheronian deposits and contains Bakuvian-type ostracodes, resembling thus the Bakuvian deposits. It makes no sense to exclude, as it was suggested, the Tyurkyanian and all other continental formations from the Caspian Pleistocene despite the fact that their seaward thickness decreases and thins out.

The report by A.V. Mamedov and B.D. Aleskerov (1991) on presence of Bakuvian cardiids in the Tyurkanyan deposits is most likely a mistake. These deposits contain only microfauna of the Bakuvian type. Also noteworthy is the extinction of most Apsheronian mollusks and the appearance of Pleistocene Bakuvian cardiids during the minimum of the Tyurkyanian regression.

G.I. Goretskii (1966) and G.I. Popov (1983) recognized a deep post-Bakuvian regression on the basis of Gidroproect drilling data in the Volga Valley and Manych region. This regression, called Venedian, corresponds to the Ushtalian regression, which also separates the Bakunan and Lower Khazarian (Gyurgyanian[2]) sedimentary cycles in the Kura depression. At this time the molluskan fauna of Bakuvian type changed to that of the Lower Khazarian. Brown silts, sands, and carbonate coquinas of the Bakuvian age changed into gray silts, sands, and coarse pebble conglomerates and coquinas of the Lower Khazarian. The Lower Khazarian deposits of Caucasian coast, western Turkmenia, and Lower Volga region are considerably enriched in terrigenous material of distant transportation. This indicates considerable water enrichment of the Caspian basin rivers that may be caused by relevant deglaciation (Fedorov, 1957).

There are three abrasive and accumulative terraces along the Caucasian coast of the Caspian Sea. These terraces are 90, 125, and 160 m high respectively, and are built with coarse pebble conglomerates and coquinas that contain Lower Khazarian cardiid fauna (Fedorov, 1957). Drilling data from the Volga Valley (Goretskii, 1966) revealed the three-membered structure of the Lower Khazarian deposits as well. All this allowed me to subdivide the Lower Khazarian into three parts (Fedorov, 1972).

I suggested (following the terminology of P.A. Pravoslavlev) subdividing the sequence into the Early Lower Khazarian (or Paleosingilian), Middle Lower Khazarian (or Singilian), and Late Lower Khazarian (Kosogian) strata. The Upper Khazarian deposits, that is the terrace with *Didacna surachanica*, were displaced from the Upper-Middle Pleistocene to Lower-Upper Pleistocene. Was it correct to place the Khazarian deposits into both the Middle and Upper Pleistocene?

It should be noted here that P.A. Pravoslavlev applied the name Khazarian to the strata with *D. surachanica* Andrus. He considered the Singilian, Astrakhanian, and Kosogian deposits as separate units, and did not include them into either the Bakuvian or the Khazarian stages. But according to his personal communication (1940), the Singilian and Kosogian deposits contain Khazarian-type molluskan fauna. This was confirmed by my own investigations (Fedorov, 1953, 1957) and explains why the Lower Khazarian (Singilian and Kosogian) and Upper Khazarian (Khazarian of P.A. Pravoslavlev) deposits were first included into the Middle Pleistocene. Further studies concerning this prob-

[2] The name Gyurgyanian (after the village of Gyurgyani in the eastern Apsheron Peninsula) was first used by V.V. Bogachev and O.V. Dashevskaya for strata lying between the Bakuvian and Upper Khazarian deposits. This corresponds to the Lower Khazarian deposits of the Caspian scale (Fedorov, 1957, 1972).

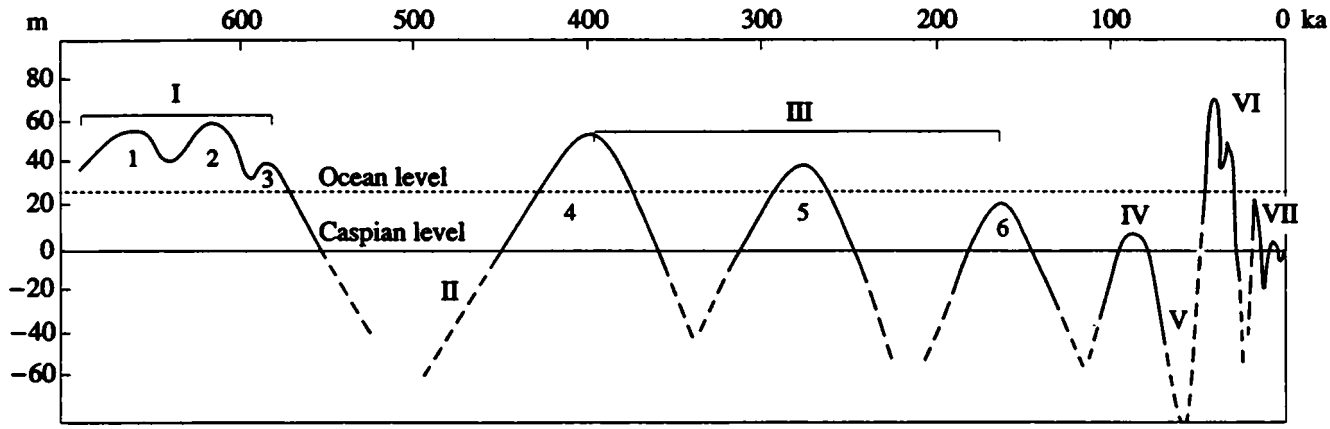

Fig. 1. Main trends in sea level changes during the Pleistocene.
I – Bakuvian transgression-regression cycle (1 – Early Bakuvian, 2 – Late Bakuvian, and 3 – Urundzhik); II – Venedian regression; III – Early Khazarian transgression-regression cycle (4 – Paleosingilian, 5 – Singilian, and 6 – Kosogian); IV – Late Khazarian transgressive stage; V – Atelian regression; VI – Khvalynian transgression-regression cycle; VII – Novocaspian transgression-regression cycle.

lem suggested that the Upper Khazarian should be transferred at the base of the Upper Pleistocene. The reasons for that are as follows:

(1) An unconformable occurrence of the Upper Khazarian coquinas above the Lower Khazarian rocks along the Caucasian coast, in the eastern Apsheron Peninsula, in the Krasnovodsk Peninsula, in Mangyshlak, and in the Buzachi Peninsula.

(2) The predominance of *Didacna surachanica* Andrus, in the molluskan fauna, though the species already appeared in upper parts of the Lower Khazarian in a paleocoenosis with trigonoid *Didacna* species.

(3) According to radiometric data, the Late Khazarian time is estimated to be 80 - 90 ka. This is slightly younger than the Karangatian of the Black Sea (90 - 120 ka). In the stratigraphic scheme of European Russia, the Karangatian, as an equivalent to the Riss-Würm, is correlated with the Thyrrenian (in a narrow sense) and corresponds to the base of the Upper Pleistocene. But using these to subdivide the Lower and Upper Khazarian deposits, we should keep in mind that they represent a single formation of coastal coarse coquinas and conglomerates (Caucasus), or coquinas and carbonate sandstones (Mangyshlak, Buzachi).

(4) The Upper Khazarian deposits contain a few carbonate-rich pebbles of rocks from the Central Caucasus. Shells of *Didacna surachanica* and other mollusks are massive and large. Some forms display giantism. In the eastern coast of the Caspian Sea coastal deposits of this age form lithified barrier beaches, bars, and spits (the Krasnovodsk bar, bars of Kara-Bogaz-Gol, and bars of Ashchi-Sor in Kankrina Bay) built with carbonate sandstones, oolites, and coquinas. Over these accumulative relief forms similar forms of the Late Khvalynian and Novocaspian age are superimposed. Rocks of the above types could have been deposited in warm waters saturated with calcium carbonate. The Lower Khazarian sediments differ from these deposits in their gray color and molluskan fauna with predominant small trigonoid *Didacna*, indicating a slight freshening of the entire basin.

Thus, biostratigraphic and paleoecologic materials suggest an essential difference in the paleogeography and age between the Lower and Upper Khazarian sedimentation basins.

The level of the Late Khazarian Caspian Sea was not as high as that of the Bakuvian and Early Khazarian basins, and likely was regressing despite the transgressive occurrence of the Upper Khazarian deposits upon the Lower Khazarian strata all along the coasts. The Upper Khazarian terraces are elevated up to the absolute height of 30 - 40 m on the coast of Dagestan[3] they are rarely higher than the zero mark in the eastern Apsheron Peninsula, being 10 - 15 m below the sea level in Mangyshlak and the western Krasnovodsk Peninsula.

Similar elevation values are known for the Upper Khazarian deposits in Volga and Ural river valleys and in drill holes in their watershed region. Such a degree of tectonic dislocation of the Upper Khazarian coastal deposits suggests that the surface of this basin was slightly lower than the sea level.

G.I. Popov (1983) recognized the Upper Khazarian deposits in the western Manych Valley. According to his data, they are overlain by Karangatian strata. Clearly this is not the Upper but older Lower Khazarian deposits, because the former have a radiometric age of about 80 - 90 ka, while the Karangatian deposits are older than 100 ka. The same is also clear from the composition of Popov's "Upper" Khazarian mollusks, among which there are many characteristic Lower Khazarian forms like *Didacna pallasi* Prav., *D. subpyramidata* Prav. and others (Popov, 1983). As to his report on *D. surachanica*, the form is known from the Lower Khazarian as well. Still, the real Upper Khazarian deposits stretch along the Manych depression toward the Azov Sea depression. In Popov's terminol-

[3] Here everywhere overlain by the Early Khvalynian deposits.

ogy (1983) these are the Hirkanian strata. The strata occupy the same stratigraphic position as the Upper Khazarian deposits in the Caspian region. The former are essentially identical to the latter. There is evidence of Upper Khazarian deposits in the western Taman' Peninsula. Here, near the village of Il'ichevka a 2-m-high terrace is superimposed on the 7-m-high Karangatian terrace with impoverished Mediterranean malacofauna. Its deposits contain small *Didacna* ex gr. *ebersini*, *Dreissena*, and *Cardium edule* L. redeposited from the Karangatian terrace. Apparently, these are the freshwater facies of the Upper Khazarian deposited at an initial regression stage of the Karangatian sea. At that time the Azov Sea depression was a flow-through basin of low salinity, receiving brackish water from the Late Khazarian sea, discharging through the Kertch' strait into the Black Sea. However, the Early Khvalynian age of this terrace is also admitable.

Thus, the one way discharge of Caspian water along the Manych strait into the Azov-Euxinian depression that took place during the Bakuvian and Early Khazarian times also occurred in the Late Khazarian. Whereas the Karangatian transgression in the Black Sea corresponded to the Riss-Würm optimum, the restricted Late Khazarian transgression corresponded to the final stage of this interglacial. It may be correlated with a final stage of the Thyrrenian in the Mediterranean Sea. There are indications of post-Karangatian warming in the eastern Kertch' Peninsula, in the well-known Eltigen sequence. Here, just upon the top of the Karangatian deposits there is a rather thick reddish-brown paleosoil. The illuvial beds of this buried soil penetrate into the weathered beach sands of the Karangatian.

If the concept presented is correct, the maximum of the Karangatian transgression in the Black Sea corresponds to the regressive phase in the Caspian Sea at the boundary between the Lower and Upper Khazarian. Geological proof on this regression is quite distinct.

During the Late Khazarian, the accumulation of coastal material proceeded through at the region, and recorded a stable state of the sea level with frequent and insignificant oscillations. On the Caucasian coast (eastern part of the Apsheron Peninsula), and particularly on the eastern coast of the sea (Mangyshlak, Krasnovodsk Peninsula) bars and sinks were formed. It is noteworthy that the Upper Khazarian deposits, at least in their typical facies, have not been encountered south of the Apsheron Peninsula and the Krasnovodsk bar. Most likely they were submerged in that very mobile part of the Caspian depression. Yet these deposits are probably present on the Iranian coast, as is evident from my finds of large reworked *Didacna surachanica* Andrus, together with shells of modern mollusks, on the beach of Ashur-Ade Island (the eastern part of southern coast of the Caspian Sea)[4].

[4] The work was conducted in 1942 during a special expedition of the Department of Geological and Geographical Sciences of the USSR Academy of Sciences.

Apparently, in the Late Khazarian the Kara-Bogaz-Gol was separated from the Caspian Sea by bars and began its own history, similar to the modern one. The Upper Bakuvian coastal carbonate sandstones and coquinas of the Omchaly Cape (western part of south coast of the bay) can, however indicate the bar position at the Bakuvian time slightly to the east of the present one.

The problem of the Kara-Bagaz-Gol and its role in the history of the Caspian Sea is a special subject. It is necessary to note only that this affected certain changes in the level of the Caspian Sea, and was a regulator of its salinity.

Paleobar formation in the Late Khazarian has led to a step-by-step isolation of the bay from the sea and to an increase in its salinity.

The Late Pleistocene and Holocene transgressions, the Early and Late Khvalynian, and Novocaspian, transformed the Kara-Bogaz-Gol into an open bay with a normal Caspian salinity. This undoubtedly led to the dissolution of some salts accumulated in regressive periods and an increased salinity in the entire sea. To the contrary, during the regressions the bay's depression converted into an isolated or semi-isolated basin with intensive salt accumulation, during which the Caspian Sea decreased in water salinity. The well-known Russian naturalist and traveler G.S. Karelin entered the Kara-Bogaz-Gol aboard the ship in 1832 - 1836 (Karelin, 1883). Apparently, the bay was not then very saline, for, according to Karelin's words, "Turkmenians fished for sturgeons." In 1933, the hydrography ship "Sekstan," with me among its crew, entered the bay along a narrow strait for measurements and other operations. By that time the salinity of Kara-Bogaz-Gol increased considerably, so much so that natural precipitation of sulfates permitted their industrial extraction in the bay.

The next Atelian regression in the Caspian Sea opens a new page in its history. The regression began after cessation of the Late Khazarian transgression. Apparently, it occurred simultaneously with the Kalinin Glaciation on the Russian Plain. In the Caspian region this climatic change is clearly manifested in changes in the subaerial deposits. In southwestern Turkmenia an ancient eolian relief of the sandy Mashad massif was at that time covered with a sheet of loess-like sandy loams and loams. This indicates that a vegetational cover was then developed under more humid conditions. Evidence of climatic humidity is observed on the Caucasian coast where fluviatile coarse pebble, gravels, and sandy loams overlie the Upper Khazarian coquinas. In western Turkmenia, at the foot of some elevations (Big Balkhan, the southern cliff of the Krasnovodsk Peninsula), there are thick accumulations of proluvial pebble, gravels, and rock debris. These deposits were later reworked by the Early Khvalynian Sea, and form a series of beach ridges (Fedorov, 1946). In the northern Caspian region fluviatile and covering loams of the Atelian Formation are underlain by the Akhtuba

sands. In the Manych Valley the Atelian (Gudilo) Formation occupies a similar stratigraphic position.

The Khvalynian and post-Khvalynian history of the Caspian Sea is well studied, by me among others, and seemingly requires no additions. Nonetheless, abrupt changes in the level of the Caspian Sea in recent years are intriguing and even disturbing, and call attention to the problem of Caspian transgressive and regressive cycles in the Late Pleistocene and Holocene as the basis for an appraisal of its modern state and a future prognosis.

The Khvalynian terraces and paleobeach ridges left almost intact by tectonic movements provide sound data for judging recent changes of the Caspian Sea level.

Two main transgressive and regressive cycles can clearly be recognized, the Early and Late Khvalynian cycles separated by the inter-Khvalynian (Enotaevian) regressive phase. This phase correlates with deltaic silts and sands of the Messerian Plain in southwestern Turkmenia, takyr sandy loams and loams at the foot of the Big Balkhan, an incision valley in the second terrace of Volga River and so on (Fedorov, 1957). The Early Khvalynian cardiids have a characteristic small size, and are rather diverse. They are represented mainly by *Didacna cristata* Bog., *D. ebersini* Fed., *D. parallella* Bog. var. and also by *D. protracna* Eichw., a form typical of the northern Caspian region. The latter form indicates a certain general freshening of the whole basin. Some Khazarian relicts still survived at this time in refuges of small bays of the southwestern coast of Mangyshlak and limans of the Ergeny region (*D. zhukovi* Fed. and others).

The Late Khvalynian cardiids are represented mainly by large *Didacna praetrigonoides* Nal. and more rare *D. subcatillus* Andrus. In Mangyshlak these forms are common in carbonate sandstones and oolites. At the very end of the Late Khvalynian a rather diverse biocoenosis appeared in coastal shallow waters. The endemism of Caspian molluskan fauna is clearly manifested in older forms surviving in subsequent (younger) basins. At the same time the appearance of new, younger forms is related to a previous historical period. This does not mean, however, that the fauna cannot be used for a detailed stratigraphic subdivision of the Bakuvian, Khazarian, and Khvalynian deposits. Svitoch's recent paper (1991), where he argues that a sequence of molluskan assemblages is useless for recognizing the Lower and Upper Bakuvian, Lower and Upper Khazarian, and Lower and Upper Khvalynian deposits seems to be incorrect.

A trend in the changes of the Caspian Sea level can be reconstructed on the basis of heights of accumulative and abrasive terraces and beach ridges. Up to 5 - 6 Early Khvalynian coastlines can be recognized in a number of places (the foot of the Big Balkhan and so on). Their most stable levels are known at absolute elevations of 47 - 48, 32, 22 - 25, and 14 m (that is at 76, 60, 50 - 52, and 42 m above the Caspian level respectively). They are almost untouched by tectonics and these levels are traceable all along Caspian coasts.

There are three Late Khvalynian coastlines. They are at elevations of –2, –11, and –16 m [26, 17, and 12 m above the Caspian level (–28 m) respectively], and are unaffected by vertical movements, reflecting thus the original level of maximum transgressions phases.

The low levels that separate them can be evaluated indirectly, and were presumably up to dozens of meters below the modern sea level. More reliable data is known for the post-Khvalynian or Mangyshlak regression in M.M. Zhukov's (1945) terminology. The sea level drop is estimated as –50 m (or 22 - 23 m below the modern sea level). Most students believe that during the inter-Khvalynian (Enotaev) regression the sea level dropped even lower than –100 m or more.

All data on the Khvalynian terraces was used to plot a curve of sea level oscillations. The Late Khvalynian and Novocaspian time is substantiated by ^{14}C datings (Rychagov, 1977). Whereas for the Early and Middle Pleistocene only the major transgressive and regressive cycles were revealed, for the Khvalynian and post-Khvalynian history more details of sea level changes were reconstructed with transgressive maxima estimated within an accuracy of one meter. Nevertheless, as no precise values of regressive levels are known the presented curve (Fig. 2) is schematic. Besides, transgressive and regressive fragments of the curve are shown in averaged form, though in reality they are complicated by minor fluctuations. Variations of the Caspian sea level during the Khvalynian and post-Khvalynian time reflect global climatic changes and primarily the growth and degradation of the last continental glaciation.

The age of terraces with levels between –2 m ("zero") and –16 m is estimated in the range from 14 to 10 ka, the Mangyshlak regression is as old as 8 - 9 ka, and the first stage of the Novocaspian transgression is usually dated as 6 - 6.5 ka, more rarely as 5 - 5.5 ka old (Rychagov, 1977; and others).

A comparative geomorphological analysis of the Late and Early Khvalynian terraces suggests that the Early Khvalynian transgression is of considerable age, thus the radiocarbon datings of 11 - 12 ka level, sometimes cited in the literature for its maximum phase, should be disregarded. Most likely, the Early Khvalynian transgressive cycle corresponds to the degradation time of the Kalinin glaciation (Würm 1) and to a substantial part of the Mologa–Sheksna interglacial. The inter-Khvalynian (Enotaevian) regression correlates to the last Upper Pleistocene glaciation (Würm 2). This should be explained in more detail. The lacustrine hydrological regime of the Caspian Sea was characterized by an increase in its water volume (transgression), i.e., by a positive water balance with an abundant supply of thawed glacial water. The event began during the accumulation of the Atelian Formation and its stratigraphic equivalents, that is, 60 - 70 ka ago. Taking into consideration the accumulation time of the formation, one can suggest that the maximum of the Early Khvalynian transgression is slightly younger than 50 - 45 ka. If that is so, regressive phases of the Early Khvalynian

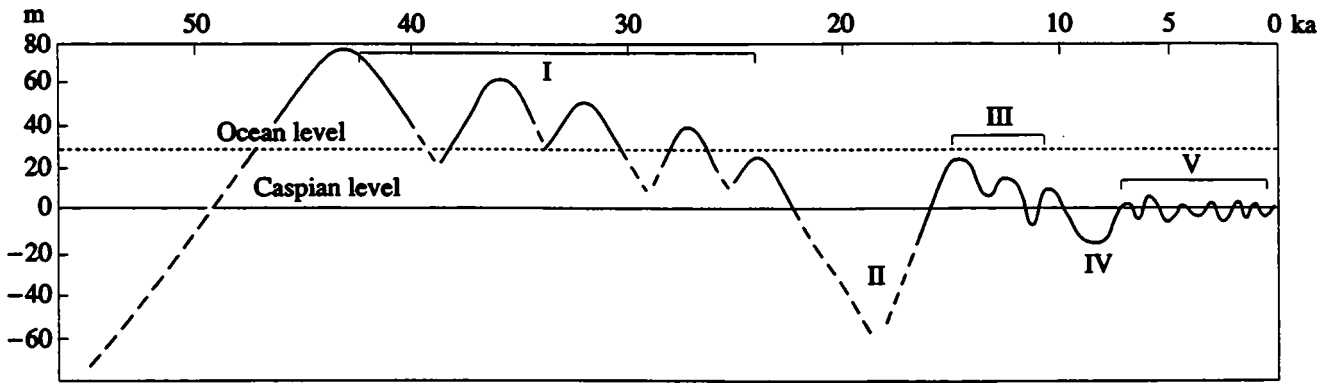

Fig. 2. Schematic curve of the Caspian level changes in the second half of the Late Pleistocene and Holocene.

I – Early Khvalynian transgression-regression cycle; II – inter-Khvalynian (Enotaevian) regression; III – Late Khvalynian transgression-regression cycle; IV – Mangyshlakian regression; V – Novocaspian transgression-regression cycle.

basin fall within the time interval from 40 - 45 to 22 - 25 ka.

The view that Caspian transgressions correspond to glaciations and its regressions match interglaciations (Varushchenko *et al.*, 1982) meets objections from a wide range of geological and paleogeographic data. On the curve of sea level changes, the ascending parts correspond to a positive balance, the maxima reflect the climate optima followed by the transition to a negative balance. Any regression that developed when the evaporation exceeded the water supply. The next ascending part of the curve marks a new increase in humidity and apparently a fall in temperature. During this stage at the very beginning of the next transgression the sea level is still extremely low (regressive), whereas sediments are accumulated under new, humid conditions.

It is well known that a considerable global climatic warming occurred 9 - 10 ka ago. It caused an acceleration of the Flandrian transgression of the ocean and Mediterranean Sea. The climate warming led to the formation of the lower Bosporus current, supplying the Black Sea with salty waters and marine fauna some 8 - 9 ka ago. The Mangyshlak regression has a definite relation to this warming and climate aridisation in the Caspian region. Subsequent development of the Novocaspian transgression-regression cycle was controlled by climatic changes in the Middle and Late Holocene. It should be noted that after the extreme level at −22 m about 6 ka ago the Caspian Sea surface did not rise above this value during the earlier transgressive maxima. Subsequent oscillations in the level of the Caspian Sea, historic time included, were never below −23 m and above −8 (12) m. The last historically dated regressive phase occurred in the 7th century at the time of the construction of the Derbent (Bab-El-Abvab) fortress by Iranian Khan Anushirvan. The sea level was then 4 - 5 m lower than the modern one (Apollov, 1956). The sea was also 2 - 3 m lower during the construction of a fortress on the coast of the Baku Bay near the Bail Cape ("Karavansarai") in the 13th - 14th centuries. In 1939, together with V.P. Zenkovich, I first identified these and others, likely older levels of the Holocene Caspian Sea on the bottom of the Alexander Bay (Mangyshlak), using a light diving equipment. Perfectly preserved wave-cut benches were observed at depths of 4, 8, and 12 m below the 1939 level. Later investigations revealed these and lower level markers along the Dagestan and Mangyshlak coasts.

The review of the geological history of the Caspian Sea shows that its typical feature was frequent changes in the water volume of this closed basin, related to global and local climatic oscillations. Changes in salinity and ecologically dependent molluskan assemblages were in accordance with these transgressive and regressive cycles. Evolutionary stages of molluskan fauna are most evident at major boundaries between the Akchagylian and Apsheronian, the Apsheronian and Bakuvian, the Bakuvian and Lower Khazarian, the Upper Khazarian and Lower Khvalynian, and the upper Khvalynian and Novocaspian. The last boundary is peculiar because of the appearance of *Cardium edule* (*Cerastoderma glaucum*) in the Caspian Sea. The species was passively introduced into the basin in the post-Khvalynian time (Fedorov, 1957), because the last connection of Caspian and Black seas occurred in the second half of the Early Khvalynian in the form of a one way discharge of Caspian waters along the Manych strait into the Azov Sea.

The trend in changes of the Caspian Sea level in the Late Khvalynian and Novocaspian times (Fig. 2) indicates that the modern level was steady throughout the last millenium. Apart from the extreme values in humidity (up to −23 m) and arid epoches (up to −32 m), the sea level oscillated between −26 and −28 m. The modern value of −27 m can be considered their average.

Analysis of natural processes indicates a constant lowering of the Caspian Sea level in modern geological time, at least during last 10 - 15 ka, the result of climate warming and aridisation.

There are reasons to believe that this trend will continue in the coming centuries.

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Evolution of the biosphere

New Data on Pleistocene Stratigraphy and Paleoecology of the Moscow Region

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Abstract – New data on the stratigraphy and depositional paleoenvironments of the Middle and Late Pleistocene deposits of the Moscow region are discussed. Problems concerning the stratigraphic position of the Kalinin glaciation and Odintsovo interglacial are considered. Interrelations between geological bodies were studied in four sequences of the Quaternary sediments. Diatoms, spores, and pollen were analyzed. Their age was determined using optically induced luminescence. All this allowed us to define the stratigraphic position of the studied beds more accurately, and to reconstruct the paleoecology of the Odintsovo and Mikulino basins.

The Quaternary sediments of the Moscow region have been studied in detail for many years. It was here that classical stratigraphic schemes for the Middle and Late Pleistocene deposits of the central Russian plain were established. Presently, they are widely used in geological mapping and prospecting. However, recently previous age estimations of moraines and interglacial deposits were considerably changed. Accordingly, the Geological Institute of the Russian Academy of Sciences initiated investigations aimed at a detailed and comprehensive study of several reference sections in order to reveal the real interrelations between the Pleistocene glacial and interglacial sediments and events. This article describes the Middle and Late Pleistocene deposits in the Dmitrov and Balashikha regions.

From 1987 to 1989 we studied sections of the Quaternary sediments at the northern slope of the Klin–Dmitrov range near Dmitrov. Three sections appeared to be the most complete and interesting: "Myasokombinat," "Borisova Gora" and "Borisova Gora-2" (Fig. 1, I, III, IV).

In the bucketlike open pit near Myasokombinat locality, horizontal layers of fluvioglacial sands up to 8 m thick dip gently towards its bottom. They are overlain by the Moscow (second Middle Pleistocene) moraine. Reticulate folds, microfaults, and fissures of glaciodynamic origin are visible at the boundary between sands and boulder-bearing sandy loam. A part of the moraine was removed by stripping. The remaining thickness is 3 - 4 m.

In the eastern part of the section, fluvioglacial and glacial deposits dip under the sand-pit bottom. They include a peat layer and lacustrine clays (up to 15 m thick). The lens of the lacustrine sediments has a dish-shaped form. In the marginal part, sediments are enriched in pebbles and boulders, which had been washed out of the underlying moraine.

Lacustrine-peat beds are cut by fissures into separate blocks. This indicates that the sediments were detached or dislocated during the post-sedimentation period.

Lacustrine-peat deposits are overlain by a horizontal bed of well-sorted sands. The upper part of the sands is disturbed by pseudomorphs formed during the Kalinin glaciation. Initial fissures were deformed by the advancing glacier. Reticulate folds and microfaults of glaciodynamic origin were found at the top of the sandy layer (up to 2 m thick).

All these sediments are overlain by a thin layer (0.5 - 1 m) of brown-red Kalinin moraine. Grey lacustrine silts from the underlying Mikulino beds are included into the moraine body.

Those researchers (Gitterman *et al.*, 1978) that studied this section have suggested that it may be a reference sequence of the Mikulino interglacial. We were the first to analyze diatoms from these deposits.

Among fourteen samples from this section, eleven contain diatoms from 73 taxa of 22 genera (Fig. 2). Species of the genera *Aulacosira*, *Cyclotella*, *Stephanodiscus*, *Pinnularia*, *Navicula*, and *Nitzschia* prevail in this exposure. The diatom flora is subdivided into two ecological groups: planktonic and benthic.

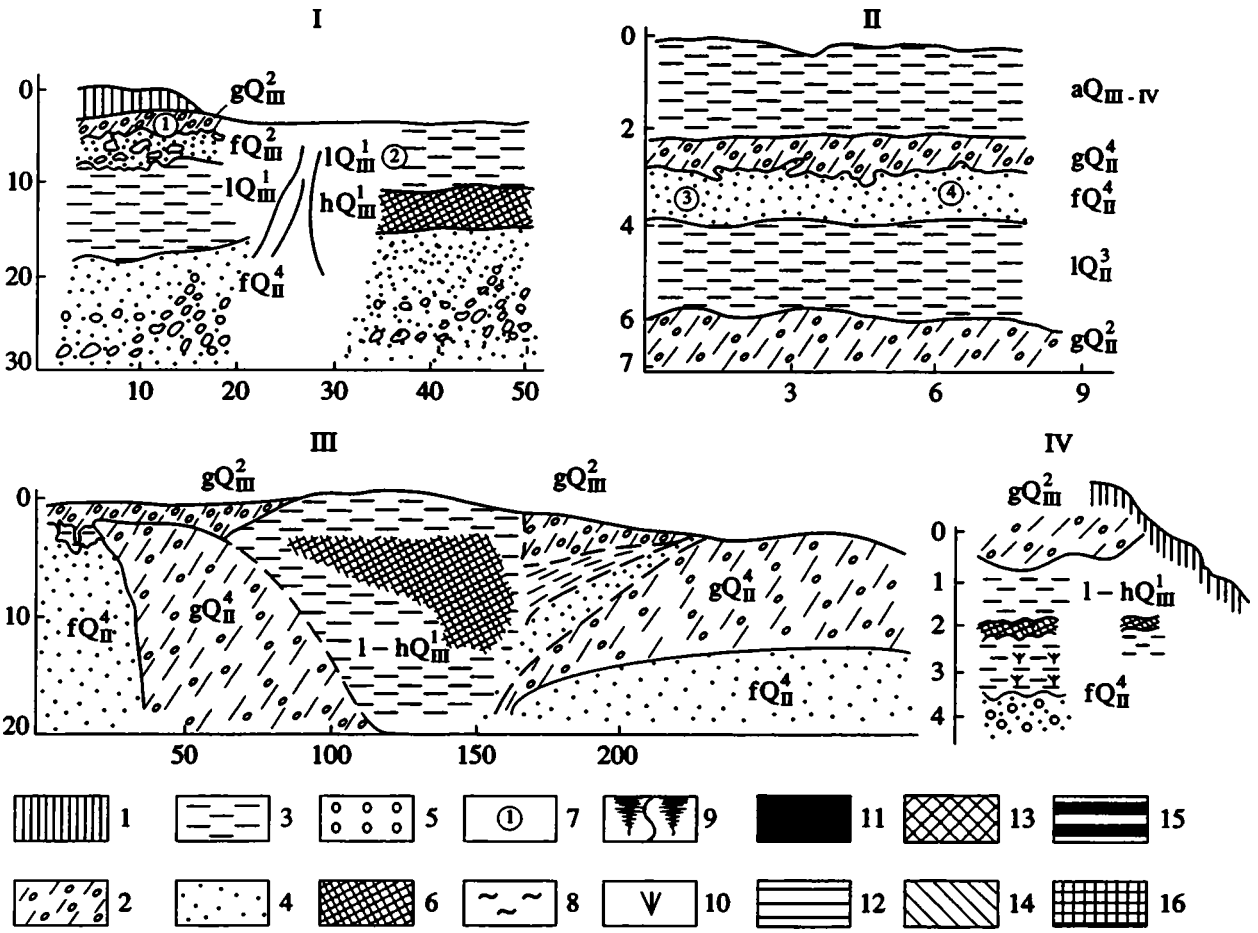

Fig. 1. Late Quaternary sections of the Moscow region.

I – Borisova Gora locality near Dmitrov; II – Krasnaya Rosa locality near Balashikha; III – Myasokombinat locality near Dmitrov; IV – Borisova Gora-2 locality near Dmitrov. Lithology: 1 – covering loams; 2 – sandy loams and boulder-bearing loams (moraine); 3 – lacustrine loams; 4 – sand; 5 – pebbles, gravel, and boulders; 6 – peat; 7 – location of the samples for photo luminescence analysis (figures in circles): 1 – sample 1108 – 65 ± 15 ka, 2 – sample 1109 – 100 ± 15 ka, 3 – sample FL-2 – 170 ± 15 ka, and 4 – sample FL-1 – 170 ± 15 ka; 8 – muds; 9 – soil; 10 – plant remnants. Ecological groups: 11 – plankton; 12 – bottom species; 13 – epiphytes; 14 – bog and lacustrine-bog species; 15 – river and spring species; 16 – soil species.

Planktonic species are not diverse, and include only 15 species of 7 genera: *Aulacosira, Melosira, Cyclotella, Stephanodiscus, Synedra, Asterionella,* and *Nitzschia*. The total content of planktonic species is less than that of benthic forms, varying from 5.5% to 56.6%.

Planktonic species in the lower part of the section are rare. They are represented by *Aulacosira italica* and species of the *Stephanodiscus* genera. Their abundance increases upwards, reaching its maximum at the depth of 4.75 m, after which it steadily decreases. A new population growth is found in the silts overlying the peat located at the depth of 1.45 m, where various forms *Aulacosira, Stephanodiscus,* and *Cyclotella* were identified.

The benthic group includes bottom diatoms and epiphytes. The benthic forms are more diverse and abundant, being represented by 58 species and varieties. Their content varies from 43.4% to 94.5%. Among bottom species, the *Navicula* and *Nitzschia* forms are the most abundant and diverse. They predominate within the upper part of the section. In the lower one, representatives of *Pinnularia, Ellerbeckia arenaria,* and *Cyrosigma* sp. occur intermitently.

Epiphytes are also diverse. Species of the genera *Gomphonema, Fragillaria, Achanthes, Synedra, Cocconeis,* and *Eunotia* are the most abundant.

A dominant group of rheophylic species occurs throughout the section, but is the most abundant in its middle part. The species are represented by different *Navicula* (*N. cryptocephala* and v. *veneta, N. exiqua, N. gracilis, N. hungarica* v. *capitata*), *Cyclotella meneginiana, Meridion circulare, Diatoma elongatum* v. *tenue,* and *D. vulgare*; the latter three found only in the lower part of the section.

Lacustrine-bog and bog species are concentrated in the lower (*Melosira arenaria, Tabellaria flocullosa,* and *Eunotia sudetica*) and upper parts of the section

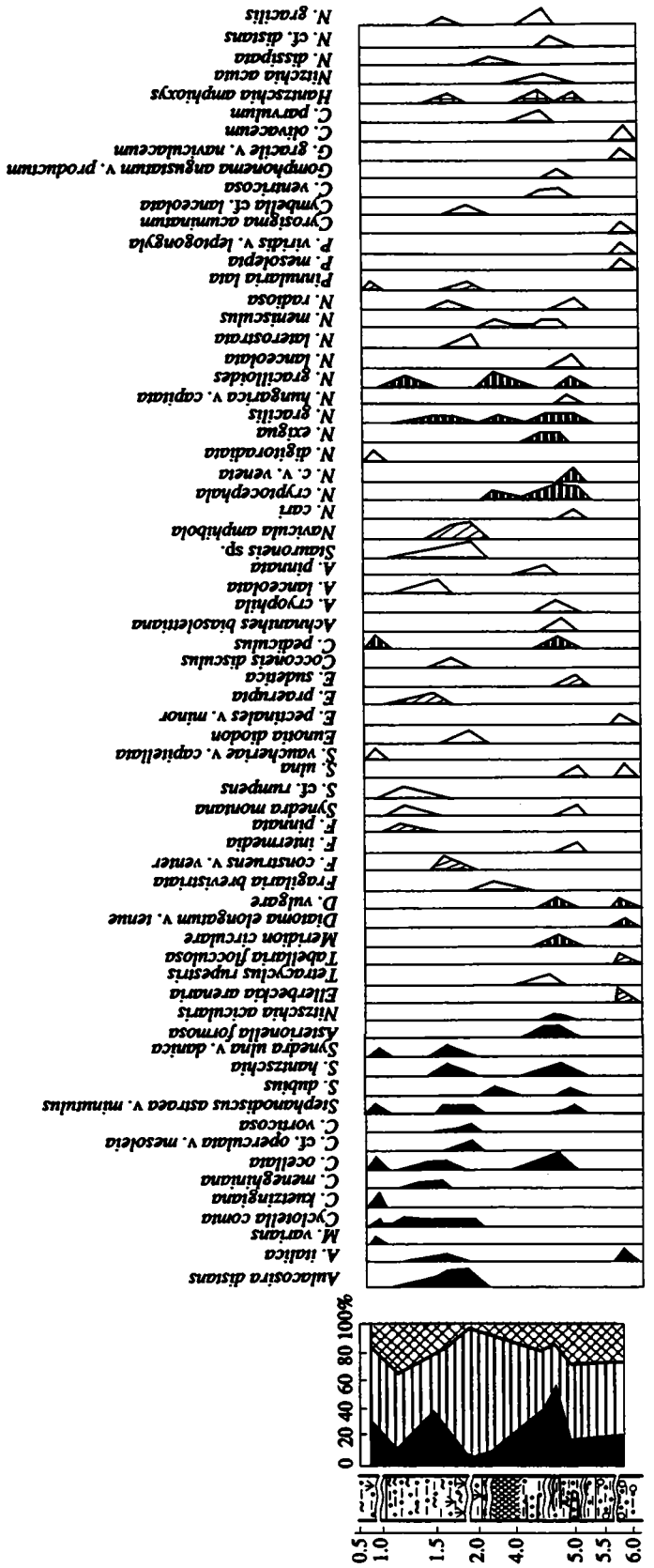

Fig. 2. Diatom distribution diagram for the Myasokombinat locality section. (Symbols for lithology see at Fig. 1).

(*Fragillaria comstruens* v. *venter*, *F. pinnata*, *Eunotia praerupta*, *Navicula amphibola*, and *Pinnularia lata*). They are less abundant than the rheophylic species. The soil species *Hantzschia amphioxys* is restricted to the peat and peaty silt of the middle part of the section, thus indicating certain exsiccation at the time of their accumulation.

In general, the diatom flora has a fresh-water character. It is represented by those species of oligohaline environments that were able to survive a salinity of 0.01 - 0.5%, among which indifferent species predominate (0.2 - 0.3%). Halophilic species (0.4 - 0.5%) *Cyclotella kuetzingiana*, *Cocconeis pediculus*, *Navicula hungarica* v. *capitata*, *N. menisculus*, and others occur throughout the section, except in the 1.45 - 3.75 m interval. Their number grows towards the top of the section. Also, rare haloxene species *Cyclotella vorticosa*, *Tabellaria floculosa*, *Meridion circulare*, *Eunotia pectinalis* v. *minor*, and *E. praerupta* were found.

Marine forms *Paralia sulcata*, *Grammatophora marina*, and *Rhabdonema arcuatum* were recorded at the depth of 1.55 m. They were probably redeposited from the older beds.

Cosmopolitan species predominate within the assemblage, though boreal forms are also abundant. The cosmopolites are uniformly distributed throughout the section, reaching their maximum content (62.5%) in its middle part at the depth of 3.75 m. Cryophilic north-alpine species constitute only a small part of the diatom assemblage, being most abundant at the depth of 1.45 m. *Melosira distans*, *Synedra montana*, *Navicula amphibola*, *Pinnularia lata*, and some other forms are the predominate species among them.

Analysis of the ecological peculiarities of the diatom flora revealed that originally the Myasokombinat locality basin was a shallow oligotrophic lake. This is proven by the presence of reophyles, rare planktonic, and more abundant benthic forms. Subsequently, with the rise in lake-level the basin turned into a eutrophic lake. The presence of various epiphytes suggested the existence of higher water plants in it. Gradually the lake was overgrown, and the peat bog appeared. Soil species indicate its exsiccation stages. A new stage in the evolution of the paleobasin was related to a climate humidification. An increase in the abundance of planktonic species marked the deepening and eutrophication of the basin at this time.

The evolution of the paleobasin environments corresponds to changes in the climate, landscape, and other paleogeographic parameters, which is indicated by a succession of the subaerial plant assemblages.

As noted above, the diatom flora indicates a rather large water basin. This is additional evidence, that the described lacustrine-peat deposits were detached from a larger original rock mass, which was destroyed by the Early Valdai (Kalinin) glacier.

The Borisova Gora section is situated nearly 3 km north of the previous exposure. Lacustrine deposits of Mikulino age, according to palynological data, overlying Mikulino peat bed (Elovicheva *et al.*, 1981) are exposed here. Data obtained by optically induced luminescence (OIL) shows that the age of lacustrine beds is 100 ± 15 ka. Their total thickness is about 8 m. Peat beds overlie the complicated fluvioglacial deposits of Middle Pleistocene (Moscow) age.

The lacustrine Mikulino deposits underlie poorly sorted fluvioglacial sediments (sandy loam, sand, and boulders) with a total thickness of 1 - 1.5 m. The latter are overlain by a reddish-brown moraine of Kalinin age, as the sand layer within the moraine yields an OSL age of 65 ± 15 ka. Dislocations and lamination of the underlying fluvioglacial deposits indicate the glacial origin of the moraine horizon. A boulder pressed by glacier into the fluvioglacial sediments and host rock microlayers surrounding it are observed in the exposure.

So, a marginal zone of the Kalinin glacier was situated near Dmitrov. The Kalinin–Dmitrov range was the obstacle that stopped the weak Kalinin glacier. No Late Pleistocene moraines have been found to the south of the studied area. The kame-and-kettle topography of the stagnant ice zones is typical of the Taldom lowland, located north of Dmitrov.

The lacustrine sediments overlying the peat beds were sampled at 20 points. Diatoms are present in 9 of them. They belong to 49 species and 19 genera, among which *Aylacosira*, *Cyclotella*, *Fragillaria*, *Eunotia*, *Navicula*, and *Cymbella* are the most abundant (Fig. 3).

Planktonic diatoms constitute only a small part of the total diatom number (from 1.3% to 33.3%) with a maximum (60%) at the depth of 5.2 m. Their maximum taxonomic diversity is observed within the lower part of the section above the peat bed. Various representatives of *Aylacosira*, *Cyclotella*, and others occur here. *Stephanodiscus hantzshii* and *Tabellaria fenestrata* are the only forms in the upper part of the exposure. The list of planktonic flora includes 13 species and 6 genera.

The overwhelming majority of diatoms belong to the benthic group (from 66.7% to 98.7%). It includes 36 species and 16 genera.

Epiphytes prevail among benthic forms of this section (20 species and 7 genera). Different epiphytic species gradually replace each other within the section. *Diatoma vulgare* v. *lineare*, many *Eunotia*, and several *Cymbella* occur in the lower part of the section. The middle part is the richest in epiphytes – *Meridion circulare*, *Fragilaria*, *Synedra ulna*, *Cocconeis placentula*, and *Cymbella* are known here. The abundance and diversity of epiphytes decrease upwards.

The lacustrine-bog and bog diatoms are uniformly distributed throughout the section. *Fragilaria construens* v. *venter*, *F. pinnata*, *Eunotia faba*, *E. lunaris*, and others are the most abundant among them.

Fluvial species are rare and include singular *Meridion circulare*, *Diatoma vulgare* v. *lineare*, and several *Navicula*. The soil species *Hantzschia amplioxys* occur in the lowermost part of the section, in the peaty silts grading into peat.

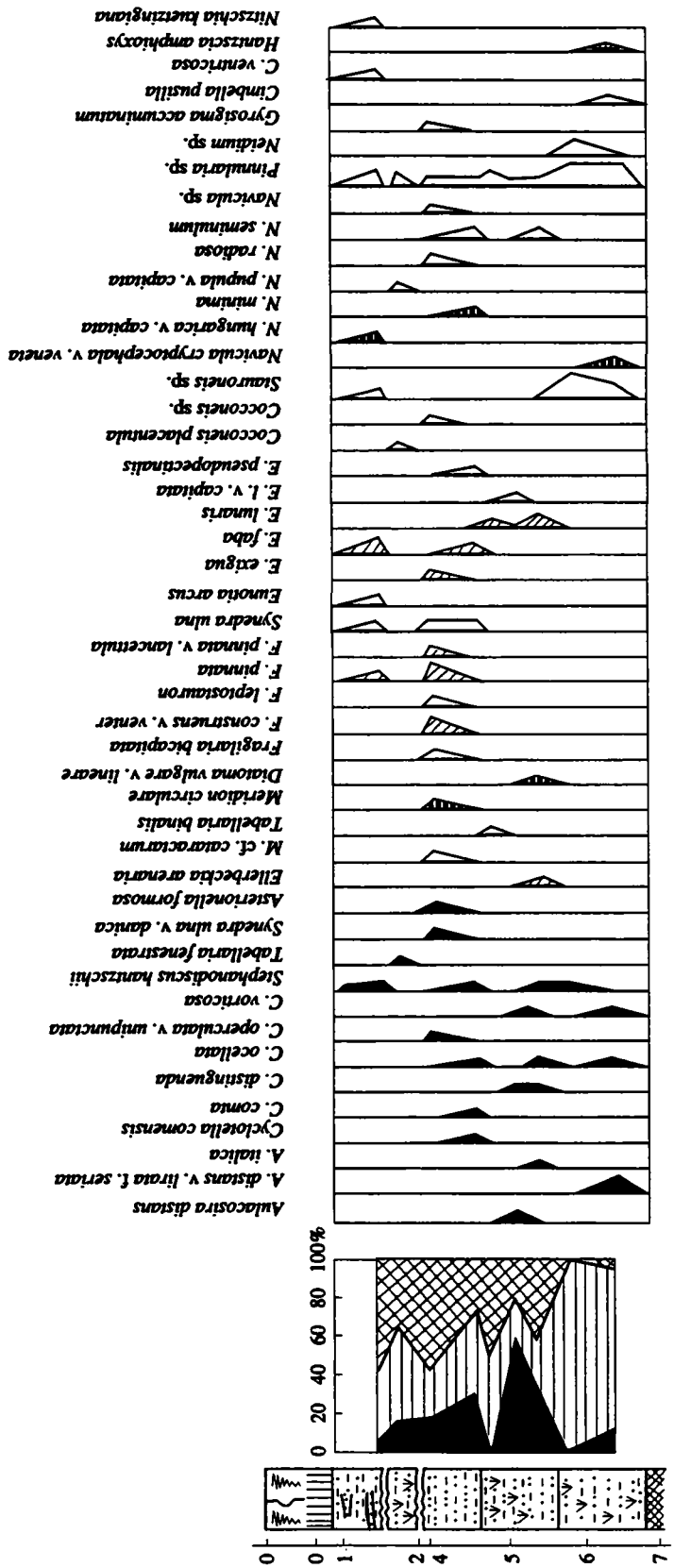

Fig. 3. Diatom distribution diagram for the Borisova Gora section. (Symbols for lithology see at Fig. 1.)

This diatom flora has a fresh-water character with indifferent species prevailing in it. Halophilic species are restricted to the lower part of the exposure. *Cyclotella distinguenda*, *Navicula cryptocephala* v. *veneta*, *Cymbella pusilla*, and others were found there. The haloxene species *Cyclotella vorticosa*, *Tabellaria fenestrata*, *Fragillaria bicapitata*, *F. leptostauron*, *Eunotia faba*, and *Cymbella gracilis* occur throughout the section.

As for acidophilic characteristics the diatom assemblage is monotonous and includes only alkaliphiles and indifferent species. The rare acidophile forms *Aulacosira distans*, *A. distans* v. *lirata* f. *seriata*, and *Eunotia faba* occur throughout the exposure, while the alkalibiontic form *Cymbella leptoceras* appears in its middle part.

The cosmopolitan diatom species are the most widely distributed. The north-alpine and boreal forms are less abundant. *Cyclotella ocelata*, *Fragilaria pinnata*, and others predominate among the boreal species. The cryophilic forms are numerous within the lower part of the section. Such northern diatom species as *Aulacosira distans* v. *lirata* f. *seriata*, *Cyclotella distinguenda*, *C. vorticosa*, *Eunotia faba*, *Cymbella gracilis*, and others are rather abundant here.

Initially, the diatom flora was overtopped, because the Borisova Gora locality paleobasin was originally a peatbog. Diatom assemblages changed upward in the section, where numerous epiphytes and lacustrine-bog species appeared, while rheophiles became nearly absent. Such diatom assemblages characterize a small eutrophic lake or a marginal part of a greater basin with abundant higher water plants.

Gradually the basin gained the features of a distrophic lake, as indicated by a predominance of bog and soil epiphytes in the diatom assemblage and by the absence of planktonic species.

The diagram showing diatom distribution along the Borisova Gora locality section seems "to continue" that of the Myasokombinat locality section. The general evolutionary tendency of the paleobasins in the Dmitrov region (oligotrophic lake–eutrophic lake–distrophic lake) resembles that of the Belarussian basins of the Mikulino age (Khursevich, 1979, 1982, 1986). Morphologically, the diatom flora of the Dmitrov region does not differ from the modern one, and has no extinct species. All this together with the position of diatom-bearing layers between glacial deposits suggest that they are of Mikulino age. As a whole, basins of both regions are characterized by boreal diatom flora, and their variations in abundance of the cold-water species correspond to palynological data (Fig. 5).

In 1992, during our investigations in the Dmitrov sand-pit, we studied one more section, Borisova Gora-2, which is 200 m from Borisova Gora proper. Here a lens of interglacial sediments underlies the boulder-bearing moraine loams. A thin soil layer (5 - 10 cm) is at the top of the lense. The layer overlies dusty white sandy loam with an apparent thickness of 1.0 - 1.5 m, the rest is covered by a talus. Two meters below, a peat with the plant remnants is exposed over the brown peat-bearing silts. Downwards they are interbedded with dense bluish-grey loams. The latter are exposed also at the bottom of the lens. Interglacial beds overlie fluvioglacial sands and pebbles.

Golubeva (Fig. 4) analyzed the spore and pollen composition of the interglacial beds. Three zones are seen in the diagram (from top downwards):

(1) A forest-steppe zone with birch, alders, and an admixture of lime-tree, oak and maple; coniferous forests.

(2) A broad-leaved forest zone with lime-tree, oak, hornbeam, maple, and hazel undergrowth.

(3) A zone of coniferous – broad-leaved forests, with hazel undergrowth.

These zones resemble palynozones M_3, M_4, and M_5 of the Mikulino interglacial described by V.P. Grichuk (1961).

Analogous spore-pollen diagrams, characteristic of the Mikulino time, were plotted for the Borisova Gora and Myasokombinat sections (Fig. 5) (Gitterman *et al.*, 1978; Elovicheva *et al.*, 1981). So, our study of the three sections in the Dmitrov region permits the age determination of the interglacial deposits. Their accumulation estimated to have occurred during the Mikulino time. Then they were dislocated and dismembered by the Kalinin (Late Valdai) glacier. Moraines of this age are present in all sections.

We also studied an exposure on the Pekhorka River in the vicinity of Balashikha, namely near the Krasnaya Rosa health center. In the river bank (2 - 3 m high) two moraine layers and inter-moraine greenish-grey sands and sandy loams overlying clays are exposed. The lower moraine layer is represented by boulder-bearing sandy loams. Its apparent thickness is about 1.5 m. The 0.5-m-thick moraine consists of sandy loams with small boulders of crystalline rocks and numerous sand lenses and pockets. The moraine layer is entirely dislocated, and has lobe-shaped penetrations inside the underlying sediments (Fig. 1, II). Two km downstream the upper moraine is replaced by sands of the long outwash valley opening into the Meshchera outwash plain.

The exposure is at the boundary limit of the Moscow glaciation,which explaines the character of the upper moraine and its small thickness.

Inter-moraine sediments consist of lacustrine and fluvioglacial deposits corresponding in age to the end of Dnieper glaciation and the beginning of the Odintsovo interglacial. Dating of the sediments by the OIL method, made by G.I. Khyutt in the Estonian Academy of Sciences, confirms the above age estimations. The obtained age value is 170 ± 15 ka, which, based on existing chronological scales, corresponds to the Odintsovo interglacial interval (Krasnov and Zarrina, 1987).

Because deposits of the Krasnaya Rosa section have neither spores nor pollen, their diatoms are the most revealing. The diatom assemblage found in the interglacial beds includes 57 taxa of 22 genera (Fig. 6). *Fragi-*

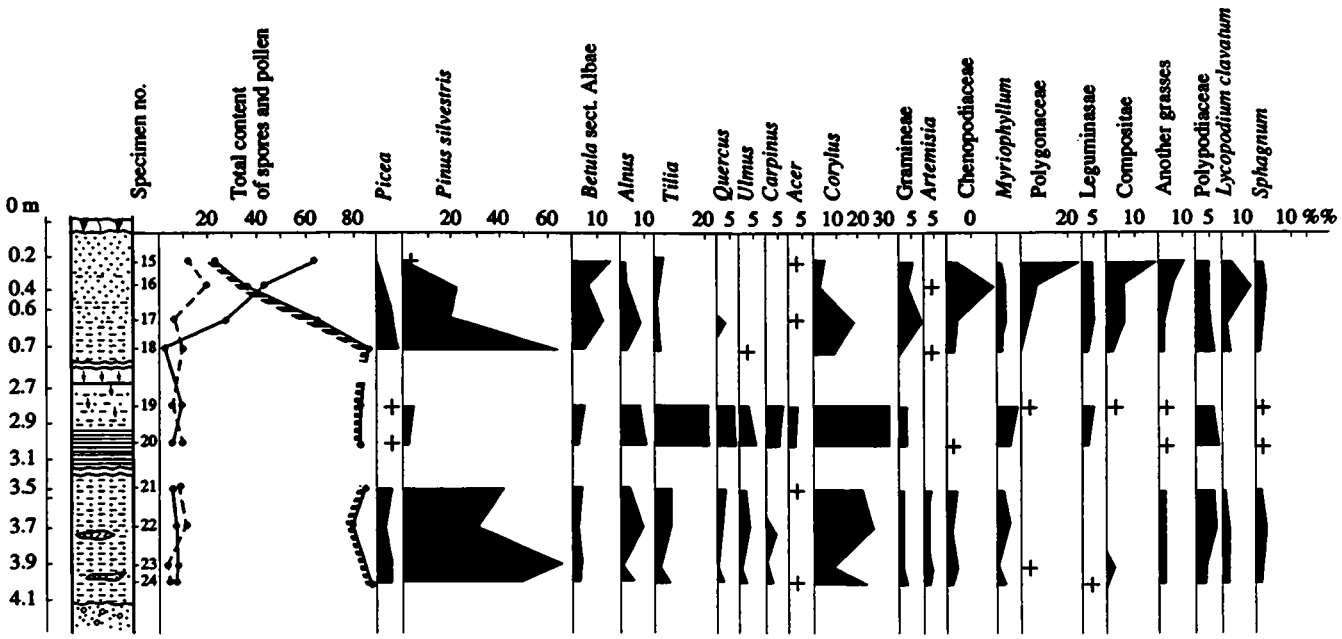

Fig. 4. Spores-and-pollen distribution diagram for the Borisova Gora-2 section.
(Symbols for lithology see at Fig. 1 and curve symbols on 5.)

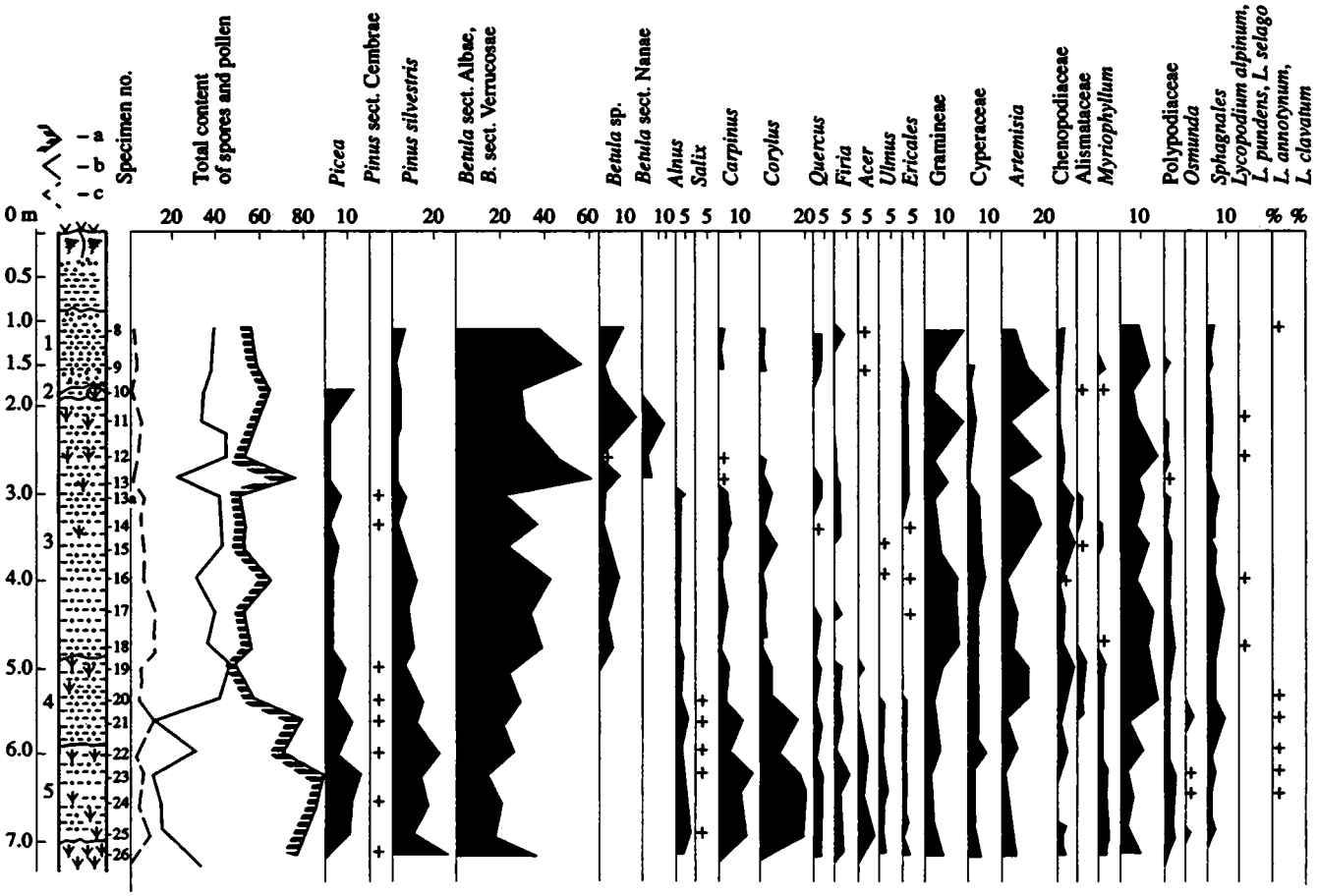

Fig. 5. Spores-and-pollen distribution diagram for the Borisova Gora section.
a – Tree pollen, b – herbaceous pollen, and c – spores. (Other symbols for lithology see at Fig. 1.)

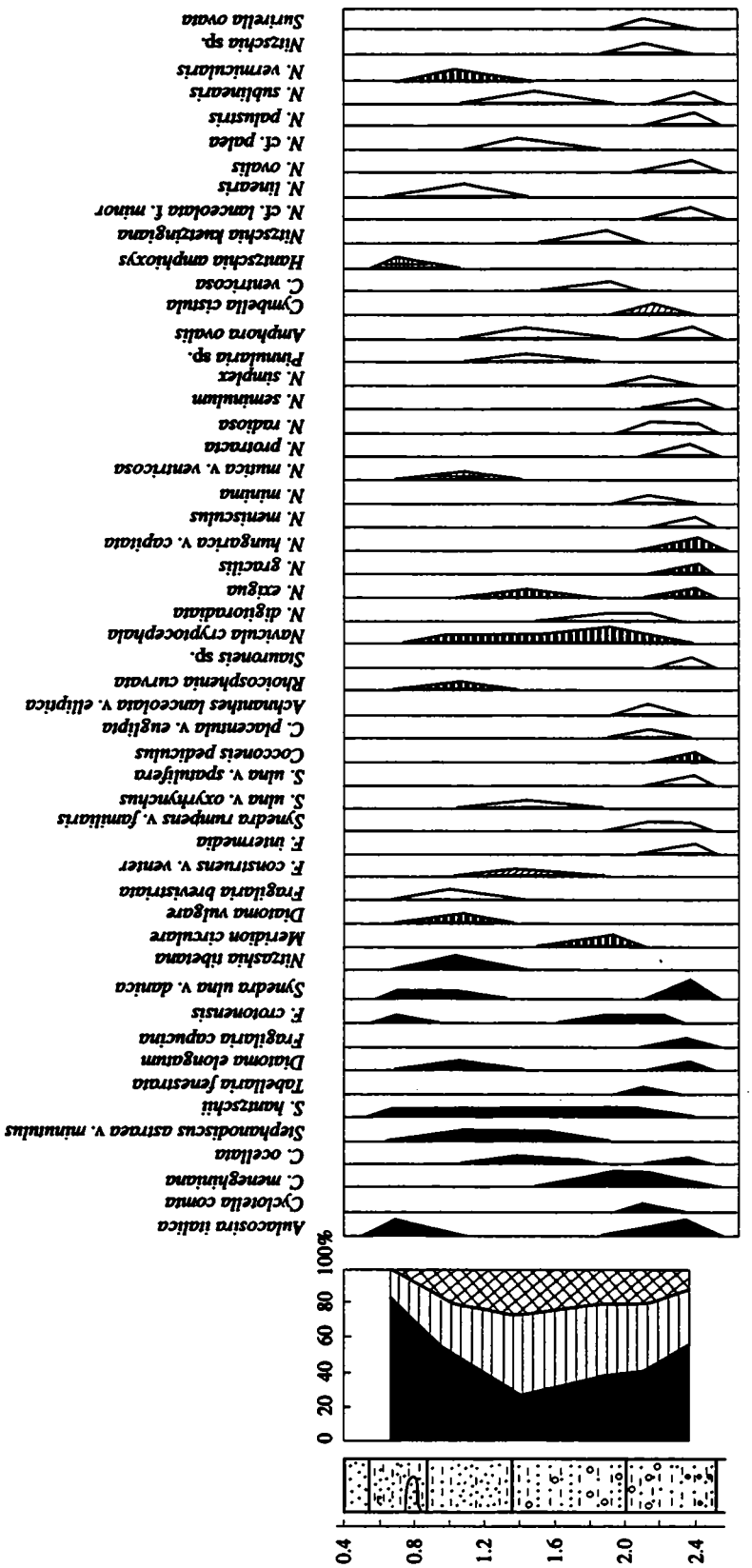

Fig. 6. Diatom distribution diagram for the Krasnaya Rosa section. (Symbols for lithology see at Fig. 1.)

laria, Synedra, Navicula, and *Nitzschia* genera are the most diverse.

The plankton group includes 12 species of 8 genera, and varies throughout the section in abundance and composition, being most diverse in its lower units. *Aulacosira italica, Cyclotella meneginiana,* and *Synedra ulna* v. *danica* are predomint.

The abundance of diatoms and their diversity sharply decreases in the middle part of the section, and again increase at the top. In general, the proportion of planktonic species in the diatom assemblage varies from 27.3 to 83.3%. Correspondingly, the percentage of other forms varies from 16.7 to 72.7%, reaching its maximum in the middle part of the section.

The benthic group includes bottom forms and epiphytes. This group is more diverse than the planktonic one. The diatoms belong to 26 species of 7 genera. Species of *Navicula* and *Nitzshcia* genera, characteristic of the lower part of the section, are the most diverse.

Epiphytes are also diverse (14 species) and include different species of *Fragilaria, Synedra, Cocconeis, Cymbella,* and other genera. *Diatoma vulgare* and *Rhoicosphenia curvata* appear in the upper units.

In accordance with natural habitats, several ecological groups are distinguished within the diatoms. Diatoms-rheophiles characteristic of rivers and large lakes with currents are concentrated in the lower units of the section. They are represented by *Cyclotella meneginiana, Diatoma elongatum, Meridion circulare, Cocconeis pediculus, Navicula cryptocephala, N. exigua,* and *N. gracillis,* and spring form *N. hungarica* var. *capitata.* The amount of rheophiles decreases in the middle part of the section, where only *N. cryptocephala* and *N. exigua* occur. Towards the top of the section their abundance slightly increases: together with *N. cryptocephala* and *Diatoma elongatum, D. vulgare, Rhoicospenia curvata,* and *Nitzschia vermicularis* appear there.

In the middle part, bog and lacustrine-bog species are represented by *Fragilaria construens* var. *venter.* In the upper part of the section such typical soil species as *Navicula mutica* v. *ventricosa* and *Hantzschia amphioxys* occur.

The water salinity is one the most significant environmental factors. Species typical of oligohaline flora predominate in the section under discussion. Indifferent species (0.2 - 0.3%) are the most abundant among them. Two haloxene species, *Tabellaria fenestrata* and *Meridion circulare* (not more than 0.02%), are rarely distributed within the lower units. Abundant halophilic forms (32%), which can exist under a salinity of 0.4 - 0.5%, are characteristic of the assemblage. Their number regularly decreases from the base upwards, reaching its maximum (8 species) in the lowermost unit. They include such species as *Cyclotella meneghiniana, Diatoma elongatum, Cocconeis pediculus, Navicula hungarica* v. *capitata, N. menisculus, N. protracta, Nitzschia* cf. *lanceolata* f. *minor,* and *N. ovalis.* In addition, *Fragilaria curvata, Rhoicosphenia curvata,* and *Navicula digitoradiata* occur in the upper units of the section.

The main peculiarity of the section is the presence of marine species *Coscinodiscus* sp., *Asteromphalus robustus, Rhizosolenia* sp., and silicoflagellate *Paradictiocha polyactis* in the first layer. We consider them to be redeposited from the older deposits.

With respect to geographical zonation, the diatom assemblage does not seem to be impressive, and includes only cosmopolitan and boreal species. As a whole, it corresponds to a temperate climatic zone.

Characteristics of the assemblage suggest that the interglacial deposits originated within a floodplain. The most striking features of that eutrophic floodplain basin, i.e., abundant plankton forms, diverse bottom species and epiphytes, and numerous rheophiles, were manifested at the initial stage of its evolution.

Though the paleobasin was a fresh-water type, at the initial stage of evolution its waters were rich in various salts, which washed out the coastal bedrocks. The significant amount of halophilic species within the lower part of the section, gradually decreasing towards the top, proves this.

Main characteristics of the diatom flora, (namely the elimination of extinct forms and morphological peculiarities, along with its similarity to the modern flora) show that interglacial beds are not older than the Odintsovo period, thus confirming their previous age estimations.

So, our investigations resulted in a more precise determination of the stratigraphic position of the Mikulino and Odintsovo interglacial beds and their interrelations with glacial deposits. Field observations, study of diatom and pollen assemblages from underlying interglacial beds, and datings by optically induced luminescence revealed that the Klin-Dmitrov range represents the extreme southern limit of the Kalinin glaciation.

Several stages of the paleobasin evolution were distinguished according to paleoecological characteristics of the Mikulino diatom flora.

The OIL method provided new data on the age of the fluvioglacial deposits of the Moscow glaciation and underlying Odintsovo beds. Paleoecological characteristics of the latter were also revealed by the diatom analysis data.

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On the Principles of Establishing and Tracing Boundaries of Series and Systems (The Devonian System as a Case Study)

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Abstract – The principles and techniques of establishing and tracing boundaries of major units of the general stratigraphic scale are critically reviewed. It is shown, using the Devonian System as an example, that the series boundaries, approved by the Devonian Subcommission of the International Stratigraphic Commission (SDS) without regarding the stepwise character of organic world development and historical-geological analysis of sequences, can not be traced in the territory of Russia and adjacent countries.

The problem of establishing and tracing boundaries of geological systems and series is, undoubtfully, one of the most important problems. Here I would like to resume the discussion on the positions, principles, and techniques of tracing boundaries of the Devonian series in Russia, adjacent North Eurasian countries, and other regions.

Over the last 20 years, the Devonian Subcommission of the International Stratigraphic Commission (SDS) has done an enormous job to determine the volume of the Devonian System and series (Ziegler and Klapper, 1985; House, 1988). A great, though regionally focused, work was done by stratigraphers of Russia as well (*Nizhnii Yarus* ..., 1983; Rzhonsnitskaya, 1986, 1989, 1991; *Srednii Devon* ..., 1985; *Stratigrafiya i Paleontologiya* ..., 1988; and many others). Nevertheless, despite numerous decisions and recommendations, many theoretical and practical aspects of the Devonian stratigraphy remain rather unclear. This mostly concerns the vast, poorly studied areas of Russia and adjacent countries of Northern Eurasia.

Stage boundaries corresponding to the general subdivisions of the Devonian were rarely traced during the geological survey and mapping of various scales. Instead, boundaries of local and regional stratigraphic units (formations and horizons) are used in practice, but in any case they should be referred to a specific standard series of the geological system. Practicing geologists should be guided by stratigraphic schemes approved by the Interdepartmental Regional Stratigraphic Meetings, which, according to the requirements of the Stratigraphic Code (*Stratigraficheskii Kodeks*, 1992), are to be held no less than once every 3 - 4 years, and by geological map legends based on these schemes. In fact, though, Stratigraphic Meetings are rarely occur (for example, the last meeting on the stratigraphic schemes of Central Siberia was held in 1979). At present, the possibility of conducting regular meetings is still more problematic. Under these conditions, distinct criteria for establishing boundaries of standard systems and series are especially necessary.

It is quite evident that the greater the number of interchangeable criteria used to determine certain boundaries, the more precise their definitions in each of the regions will be. What are the criteria? In the latest issue of the Stratigraphic Code (*Stratigraficheskii Kodeks*, 1992), an idea of a unitary stratigraphy was proposed that is commonly accepted by Russian geologists, and an emphasis was placed on the fact that major stratigraphic units (consequently, standard stratigraphic units included) are geosystemic nature because they reflect a certain stage of the bio-, hydro- and atmosphere evolution. So, not only paleontological but other criteria (lithological, paleoclimatic, paleomagnetic, and others) as well can and should be used to trace systems' and series' boundaries indicative of geohistorical stages.

When considering steps in geosphere development we should agree that major and minor stages, which correspond to stratigraphic subdivisions of various ranks, have specific features. This can seemingly be applied to stages that are physically separated by boundaries of stratigraphic subdivisions of various ranks. Consequently, there should be principal differences between boundaries of zones, stages, series, and systems which can facilitate the recognition of subdivisions of various ranks. In Soviet manuals, issued prior to the Stratigraphic Code (*Stratigraficheskaya Klassifikatsiya* ..., 1965; etc.), differences between geological systems, series, and lesser units of the general scale were clearly identified and formulated. Both Russian issues of the Stratigraphic Code lack comparable definitions, and the reader is under the impression that there is no difference between boundaries of zones and geological systems. This situation seems to be the result of a consensus between two basic approaches to stratigraphic classification implemented by European and North American geologists (Zhamoida and Menner, 1974), where a major disagreement is the problem of a unified stratigraphy and natural character of stratigraphic units.

Though dismissing the standard stratigraphic scale as relative and geohistorically invalid, G.P. Leonov still admitted that "the more or less complete correspondence of most of the units of the International Scale to various stages in the development of certain regions arises from the very process of recognizing these units, and is beyond doubt" (Leonov, 1973). These specific features of traditional scale are not taken into consideration by the methodological recommendations issued by the International Subcommission on Stratigraphic Classification (*International* ..., 1976) based on the principal ideas of the North Americal Stratigraphic Code. As a result, an internationally accepted approach for elaborating the general stratigraphic scale implies a solely paleontologic framework. The arguments of European geologists against such an approach were disregarded (Menner, 1978).

However, "a natural system of units and boundaries along with the idea to trace evidence of any events in sedimentary rocks only makes it impossible to create and use specialized (lithologic, paleomagnetic, and others) scales" (Meien, 1989). According to Meien, with whom I heartily agree, any stratigraphic scale created should be based on a complex of parameters, lithological features in particular.

Disregarding the geohistorical approach, which recognizes the boundaries of major units of the general stratigraphic scale, we obtain a sharp decrease in the number of features to be used in stratigraphy. Actually, only paleontological criteria remain, which are focused on the first appearance of selected (by consensus, arbitrary) species. Consequently, practicing geologists are unable to confidently recognize and map boundaries of series and systems. Paleontological methods are undoubtedly essential in the case of the Phanerozoic, but if we want to fix boundaries of major stratigraphic units that are geosystemic in nature, we should take into account the stepwise character of the development of the organic world (Menner, 1962) and use other methods, in particular, methods of lithological formations, to objectively recognize geohistorical stages of various ranks.

The Devonian and other Subcommissions of the International Stratigraphic Commission have been done a great and very usefull work in revealing and tracing some correlation levels, but their correlation of boundaries of major units with the general stratigraphic scale is in most cases incorrect. "Global stratotype boundaries and points" of major stratigraphic units are sought in lithologically homogeneous portons of sections, where successive fauna changes are assumed to be free of environmental influences but are in accord with evolutionary laws. Rock members fitting this criteria are rarely occur in close vicinity to the series or system boundaries, but are usually confined to their middle portions. As a result, new levels appear to be noticeably displaced relative to the traditionally accepted boundaries. Once these levels are accepted as series boundaries, the law of priority is violated, and this, subsequently, leads to a destabilization and total reorganization of the general stratigraphic scale.

The negative effects of the "new" stratigraphic scales in our practice of regional geological studies can be illustrated by the Devonian System. In 1973, "The Devonian System," in two volumes, was issued as part of "The Stratigraphy of the USSR" serial. That fundamental book appeared as the result of a generalized stratigraphic and, what is most important, medium scale geological survey data collected over the course of many years of special studies all over Russia. Despite many shortcomings and errors, which are especially noticeable 20 years later, the book has become useful nonetheless. Correlating and tracing the Devonian sequences and series boundaries, respectively, in the vast territory of Northern Eureasia, scientists used both paleontological and geohistorical criteria. The job could not have been accomplished otherwise, because of the wide distribution of thick sequences with rather poor paleontologic characteristics.

The problem of the Silurian–Devonian boundary had been settled before the above mentioned book was published, and therefore is not a part of the discussion. As for the Lower-Middle Devonian boundary, which was always doubtful, localization of the lower stratotype boundary of the Eifelian Stage at the base of the *partitus* conodont zone prohibited recognition of the "Eifelian" stage s.l. in the USSR and resulted in the still unsolved problem of the lower stage of the Middle Devonian (*Nizhnii Yarus* ..., 1983). The problem is difficult if not impossible to solve because, on the one hand, the level of distinct evolutionary changes in various groups of fauna and universal change of geologic formations, being accepted as the Lower-Middle Devonian boundary in the USSR, was much lower than the Eifelian Stage base; on the other hand, the base of the Eifelian, or Middle Devonian, which according to the SDS resolution coincides with the lower boundary of the *partitus* conodont zone, can not be depicted in Russia and adjacent North Eurasian regions either by paleontological, or by geohistorical criteria.

The natural response of geologists to the disregarding of geohistorical analysis in composing stratigraphic scales was an attempt to develop new methods and such branches as the "event stratigraphy," "ecostratigraphy," "eustatostratigraphy," etc., which, in fact, bear nothing new but emphasize the necessity of a comprehensive analysis of the history of ancient basins and the relevant organic world.

An analysis of the Devonian sections in North America and Western Europe enabled Johnson *et al.* (1985) to plot an eustatic curve reflecting major transgressions and regressions of the Devonian. A similar curve was drawn by House (1985) after studies on evolutionary stages of Middle Paleozoic ammonoids. While studying the Devonian history of the Urals-Mongolian Belt and adjacent North Eurasian regions, I, apart from cited scholars, revealed several phases of sharp expansion and reduction of the Devonian basins due to eustatic variations of the sea and ocean levels, the result of tectonic processes (Karaulov, 1988, 1992). Boundaries of major transgressive-regressive cycles on the curves for

different continents coincide. This seems to indicate their planetary character. So, even with the problem of universal geohistorical periods still unsettled, data on planetary (global) events are much too important to be ignored in stratigraphic scales.

Judging by the available data, the onset of major transgressions can be attributed to the Middle Emsian and to the Givetian–Frasnian (in older terms) boundary. If one were to account for the levels of these essential geohistorical events in a subsequent correction of the Devonian series boundaries, it would be possible to recognize markers that could be easily traced all over the continents.

It is worth noting that when the problem of the lower stage of the Middle Devonian first arose, there were substantial arguments in favor of placing the Lower-Middle Devonian boundary at the base of the Couvinian (Rzhonsnitskaya, 1983) or the Dalejan (Bogoslovskii, 1983) stages. This level is very close to both the first of the above mentioned geohistorical events and the traditionally accepted Lower-Middle Devonian boundary in Russia. Of course, it was not by accident that the Couvinian Stage, including the Hierdes graywackes, appeared at the base of the Middle Devonian in the earliest schemes of the Devonian (Leonov, 1973). However, SDS voted against geohistorical arguments, and the lower boundary of the Eifelian, or Middle Devonian was attributed to the base of the *partitus* conodont zone. Rzhonsnitskaya (1986) is right when he notices that this level "runs inside an almost constant conodont assemblage and other groups of flora and fauna... It is difficult to trace the global boundaries of the *partitus* Zone."

As should be expected, subsequent stratigraphic studies have shown that any attempt to correlate the lower boundary of the Middle Devonian to the level recommended by SDS in Russia is futile. In the Urals, the Lower-Middle Devonian boundary is attributed to the base of the Irgizlian and Karpinskian horizons, which are supposed to correspond to the base of the *gronbergi* Zone (Nasedkina *et al.*, 1990); in the Salairs, that boundary is referred to the base of the Baskuskan beds, which approximately corresponds to the *inversus/serotinus* zonal boundary, or to the base of the Dalejan Stage (Gagiev *et al.*, 1987). Other scholars believe, however, that the Telengitian regiostage is located at the base of the Middle Devonian, whose base approximately coincides with the lower boundary of the Zlichovian (*Stratigraficheskie* ..., 1987). The Interdepartmental Stratigraphic Conference on the Middle and Upper Paleozoic of the Russian platform decreed that the lower boundary of the Middle Devonian coincides with the base of the Koiva Horizon of the Upper Emsian, which is coeval with the base of the brachiopod *Zdimir pseudobaschkiricus–Megastrophia uralensis* Zone, or the conodont zone *patulus* (*Reshenie*, ... 1990).

It is quite evident that all attempts to merge the Lower-Middle Devonian boundary to the level established by SDS are aimless and destabilizing. By shifting this boundary from the traditional level to the base of the *Zdimir pseudobaschkiricus–Megastrophia uralensis* Zone, the problem still remains unsettled, because this level runs one standard zone lower than the boundary authorized by SDS, and is hardly traceable everywhere.

Therefore, it is *a priori* impossible to fulfill the decree issued by the Devonian Subcommission of the Interdepartmentable Stratigraphic Commission (ISC) (*Postanovleniya* ..., 1991), and to adopt the stratigraphic scale of the Devonian System sanctioned by SDS because the recommended lower boundary of the Middle Devonian can not be traced in Russia. In my view, the best way to solve the problem would be to include the following three stages into the Middle Devonian: the Dalejan, the Eifelian, and the Givetian. SDS has already decided to include the Chekhian stratigraphic stages into units of the general scale, and the Lower-Middle Devonian boundary at the base of the Dalejan Stage is to be next to the tradional boundary, and coincides with a notable geohistorical event, not having been suggested previously without reason (Bogoslovskii, 1983; Yang Shih-pu *et al.*, 1981).

The problem of the Middle-Upper Devonian boundary is not less complicated. In Russia, so far, the boundary is reliably traced at the base of the Pasha Horizon and its age analogues (*Stratigrafiya SSSR* ..., 1973) correlate with the Fromelennes Formation base, i.e., with the traditional Givetian–Frasnian boundary. After the SDS decision to displace the lower boundary of the Frasnian Stage, i.e., of the Upper Devonian, to a much higher level (at the bottom of the conodont subzone *L. asymmetricus*) approximately coinciding with the base of the Frasnes beds, the situation has changed. Initially, Russian geologists were strongly against that decision, which seriously violated the priority law and disregarded stages in fauna and flora evolution (Rzhonsnitskaya, 1986, 1989), but judging by the decree of the ISC Devonian Commission, the efforts of SDS supporters were successful.

With this problem of the Middle-Upper Devonian boundary at hand, I carried out a comparative geohistorical analysis of the Upper Givetian and Frasnian sections of Eurasia and other continents (Karaulov, 1989, 1989). The analysis has shown that within these intervals there are several approximately isochronous levels that correspond to the onset of expansion and deepening phases of the Devonian basins. The most significant level coincides with the traditional Givetian–Frasnian boundary. This level is in the middle of the *varcus* Zone, where we observe sharp evolutionary changes in ammonoids and other fauna groups, and in on-land flora as well. House (1985) studied in particular biotic events in the evolution of Devonian ammonoids and related the "Tathanic event" to this level. I have already mentioned that one of the most intriguing rises in ocean level in the eustatic curve (Johnson *et al.*, 1985) is confined to this level of the traditional Middle-Upper Devonian boundary.

My firm standpoint is that the Middle-Upper Devonian boundary, having been for many years referred to the base of the Fromelennes Formation of the Frasnian

or to that of the Adorfian Stage because of the appearance of ammonoid genera *Pharciceras* and the archeopterian flora imprints, is most clearly indicated by the evolutionary changes in other fossil groups, which coincides with significant geohistorical events, and should be left at the traditional level. The displacement of one of the most unambiguous and traditional boundaries of global importance, sanctioned by SDS, is a dangerous precedent, violating the priority law and resulting in destabilization.

Under the present circumstances, the paradoxical decision of the (ISC) Devonian Commission that, on the one hand, recommends the adoption of the SDS-sanctioned Devonian Scale and, on the other hand, proves that it is impossible to practice the decreed stage boundaries, may be a disservice to Russian geology. The policy of compromises appropriate in politics damages science. The Russian representatives in SDS should raise their voices more loudly in favor of further investigations to correct boundaries between the Devonian stages. Prior to international agreements, it seems more reasonable to settle the problem of boundaries at the national level as is a common practice, which will not hinder regional geological studies in Russia.

Finally, I have to note some points concerning the upper boundary of the Devonian. An active discussion on the Devonian–Carboniferous boundary in the USSR resulted in the well known Minsk conference decision (sanctioned by ISC) to raise the base of the Carboniferous to the lower boundary of the reference conodont zone *sulcata* (*Granitsa Devona* ..., 1988). The decision was not universally accepted, including the author as one of the opponents (Karaulov and Grechishnikova, 1988). However, formally it may be beyond criticism because it returns us to the level close to that accepted at the 2nd Heerlen Congress and adopted by most of the European countries. Nevertheless, it is simple to use the new Devonian–Carboniferous boundary in Russia. This boundary's rank is less significant, geohistorically, than that of the previous boundary, and the problem of defining of the uppermost Upper Devonian, included earlier into the Carboniferous, as a single stage, remains.

In conclusion, it is worth emphasizing once more that disregarding geohistorical criteria in the determination of boundaries of major units of the general stratigraphic scale (which is equal to disregarding geohistoric subdivisions) leaves practical geology with few (if any) methods by which the boundaries can be globally traced, Russia included. Quite formal geochronologic scale, whose major units' boundaries are recognized by first appearances of arbitrarily chosen species, rare or absent in most of sections, is not suitable for many regions. Consequently, specialists should make a serious effort to find an optimum variant of the general (international) stratigraphic scale.

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BRIEF

COMMUNICATIONS

Palynology of the Marine Upper Pliocene in Syria and a Paleogeographical Analysis

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Palynology of both marine and continental Pliocene deposits of Syria is still insufficiently studied. Data on the reference marine Pliocene sequence Mardido is thus of considerable interest. This sequence is located in the Nahr-El-Kabir depression in northwestern Syria. The depression is filled with thick Neogene deposits. The Pliocene part of the section is composed of rather uniform clayey and carbonate deposits overlying Messinian gypsums. The overall thickness of these deposits amounts to 120 - 130 m. At present the Mardido sequence is considered to play a role in referencing the marine Pliocene of northwestern Syria. Its integrated study will enable us to substantiate paleogeographical and, particularly, paleoclimatic reconstructions.

The present paper considers mainly palynological data from the upper part of the marine Pliocene section (Fig. 1). Pollen saturation happened to be sufficient (generally more than 200 grains) for the interpretation of pollen spectra.

Palynological data indicates that the Mardido deposits are Late Pliocene in age. The general composition of the pollen spectra shows oscillations in the arboreous and herbaceous pollen ratio with a predominance of archaic arboreous pollen (more than 50%). A dominant group includes pollen of *Pinus* (56 - 88%), *Cedrus* (up to 18%), *Picea* (up to 10%), and *Abies* (up to 9%). In addition, arboreous angiosperm pollen of *Quercus*, Oleaceae, and *Juglans* occur frequently. The herbaceous group is dominated by pollen of Compositae, Chenopodiaceae, Graminae, Ranunculaceae, and Nyctoquinaceae. Spores are rare but diverse. They represent *Botrichium*, *Osmunda*, Adiantaceae, *Anemia*, *Pteris*, *Lycopodium*, and *Selaguinella*. The pollen of plants rarely occurring in recent flora of western Syria is widely represented. The group includes *Podocarpus*, *Cycas*, *Picea*, *Liquidambar*, *Eucommia*, *Magnolia*, *Fagus*, *Tilia*, *Carya*, *Osmunda*, and *Anemia*. These elements are partly redeposited. A similar composition of pollen spectra is known for the Upper Pliocene of Israel (Horowitz, 1990), Syria (Simakova, 1993), Greece (Sauvage and Dufaure, 1976), southern Italy (Zheng and Cravatte, 1986), Turkey (Benda, 1971; Horowitz, 1987), and southern France (Suc, 1978).

Foraminifers, according to V.G. Kurenkova, confirm the Late Pliocene age of the studied deposits. In the interval from 0 to 13 m *Globorotalia humerosa*, *Sphaeroidinella dehiscens*, *Globigerinoides ruber*, *G. obliquus*, and *G. extremus* were found. These forms indicate an age between 3 and 2.6 Ma for this part of the sequence. At the level of 13 m the benthic foraminifera *Hyalinea balthica* occurs. The first occurrence of this form is dated at 2.6 - 2.8 Ma according to Stainfort's scale.

Reconstruction of vegetational changes, paleolandscapes, and fossil environments is an urgent problem for modern arid subtropical regions of the eastern Mediterranean. It is caused not only by insufficient knowledge of palynology, but by difficulties in the interpretation of spore and pollen spectra that were influenced by neighboring forest mountain regions as well. Spore and pollen complexes of xerophytic vegetation corresponding to periods of climatic aridisation are reliably recognized. The same can be said for complexes typical of more humid climates. Complexes reflecting periods of warming or relative cooling are most difficult to interpret because plant associations of arid subtropics are mainly controlled by humidity rather than temperature.

Application of the eco-geographical method, based on the actualism principle, permitted us to establish which types of vegetation correspond to various climatic conditions: humid cold, humid warm, dry cold, and dry warm.

In the interval from 7 to 89 m of the Mardido sequence I established nine palynological complexes comprised by four pollen floras. Pollen spectra of the lower (0 - 7 m) and the upper (89 - 90 m) parts of the sequence are apparently contaminated with pollen of modern plants like Taraxacoceae, *Quercus*, and *Pinus*, which greatly distorts the original spectrum. These intervals are therefore not considered in the subsequent discussion.

The first palynological complex (1) from the depth interval of 7 to 12 m consists mainly of arboreal pollen. The spectra are dominated by the pollen of pines, with fir and cedar present, and with an insignificant share of *Alnus*, *Quercus*, and Taxodiacea pollen. The herbaceous group is dominated by representatives of the Graminae, Chenopodiacea, and Compositae families.

This palynological complex most likely reflects vegetation of African-type forested savannas. The main features of these are solitary deciduous trees and sometimes evergreen palms and conifers. There was no undergrowth, and well developed herbage was mainly composed of cereals because of good lighting conditions. Mountainous areas were covered with pine forest with a presence of *Picea* and *Abies*. This type of vegetation implies a high average annual temperature and a significant amount of precipitation during the rainy season that occurs from the beginning of summer to the end of autumn (Isachenko, 1989; Alekhin, 1957).

The second palynological complex (2), recorded at a depth of 12 - 30 m, is also dominated by arboreal pollen. Content of the conifers *Cedrus*, *Picea*, *Abies*, *Podocarpus*, *Cycas*, *Tsuga*, and Betulacea pollen drastically increases. Pollen of *Fagus* and *Eucommia* occur as well. The herbaceous group is dominated by cereals, Compositae, and Rosaceae. Such a pollen spectra can be formed in subtropical forested landscapes similar to the subtropical forests of East Asia (Isachenko, 1989; Alekhin, 1957) with their high diversity and high content of Tertiary relicts. These are mixed evergreen coniferous and broad-leaved forests, which are characterized by a humid and moderately warm climate with a hot and rainy summer and a cold, dry winter. The winter temperature is somewhat lower than that in arid subtropics of the same latitude.

The two palynological complexes described can be considered within a single pollen flora (1) of a significantly higher humidity as compared to the present time.

The third palynological complex (3), recorded at a depth of 30 - 41 m, is distinguished by the dominance of pines and herbs. Arboreal pollen of *Abies*, *Picea*, *Pinus* sect. *Strobus*, *Liquidambar*, *Juglans*, Oleacea, *Quercus*, and *Salix* are present in equally low quantities.

Cistus and *Ceratonia* occur only once. Herbs are mainly represented by pollen of Chenopodiacea, Nyctoquinaceae, *Ephedra*, *Crucifera*, Leguminosae, and Umbeliferae. Cereals decrease in quantity. Such a composition of spore and pollen spectrum indicates the existence of Mediterranean-type evergreen sclerophyllous forests. The lowlands were occupied by maquis associations, whereas the mountains were covered with cedar and pine forests with a presence of *Picea* and *Abies*. The middle elevations bore *Liquidambar*. Some of the present distribution area of this tree is preserved in southwestern Anatolia (Walter, 1982). The climate was similar to the modern one, being moderately cool and arid.

The fourth palynological complex (4), recorded at a depth of 41 - 45 m, is characterized by frequent and prominent oscillations in the general composition of spectra with a sharp reduction of arboreal pollen. The role of *Cedrus*, *Pinus* sg. *Haploxylon*, and *Picea* diminishes, whereas *Abies* disappears. The quantity of *Pinus* sg. *Diploxylon* pollen increases. Chenopodiaceae and Graminae are predominant among herbs. This spectra composition reflects vegetation that resembles communities of typical north African tropical savannas. The mountains were covered with pine and oak forests with an admixture of fir, whereas the low elevations were occupied by sclerophyllous evergreen forests, which suggests arid and warm climatic conditions.

The fifth palynological complex (5), recorded at a depth of 45 - 60 m is similar to the third complex. It indicates typical Mediterranean vegetation, and a moderately dry and warm climate.

Palynological complexes from 3 to 5 can be unified in pollen flora II. It comprises a depth interval from 30 to 60 m and reflects relatively arid climatic conditions.

The sixth palynological complex (6), recorded at a depth interval from 60 to 72 m, shows an increased role of arboreal pollen. The content of *Pinus* sect. *Strobus* increases, and pollen of *Cedrus*, *Picea*, and *Abies* is present in significant quantity. Pines predominate. Single grains of lime and magnolia are recorded. The share of Compositae and herb pollen also increases.

The landscapes that existed during the formation of this complex are known at present in the northern Mediterranean. Low elevations and plains were occupied by sclerophyllous forests and shrubs. Vegetation of higher elevations was represented by pine and cedar forest with an admixture of *Picea* and *Abies*. A mountainous belt formed by deciduous forms of lime, alder, birch, and beech was present as well.

The climate was more humid and somewhat colder than the modern one. It was distinguished by a humid winter and dry summer that is typical for the Mediterranean region.

The seventh palynological complex (7), recorded at a depth interval of 72 - 80 m, is characterized by a decrease in *Pinus* sg. *Haploxylon* versus *Pinus* sg. *Diplooxylon* pollen. The content of *Abies*, Oleacea, Chenopodiaceae, *Artemisia*, and Compositae increases whereas the share of herb pollen diminishes. Single occurrences of *Alnus*, *Liquidambar*, *Ostrya*, and *Juglans* are recorded. Such a spore and pollen spectrum reflects vegetation of north African maritime landscapes with evergreen forests of piedmonts giving place to mountainous pine and oak forests. Higher elevations are populated by cedar forests with a presence of holly. Relict forests of *Abies* occur on the windward slopes (Isachenko and Shlyapnikov, 1989). This type of vegetation requires a relatively humid and warm climate with seasonal moistening, which is characteristic of the Mediterranean subtropics.

The eighth palynological complex (8), recorded at a depth interval of 80 - 86 m, is analogous with the sixth complex. It suggests the existence at that time of evergreen subtropical sclerophyllous north Mediterranean forests with a slightly colder and more humid climate compared with the modern one.

Spore and pollen spectra of the last three palynological complexes reflect a relatively humid Mediterranean vegetation, which enables them to be considered within pollen flora III.

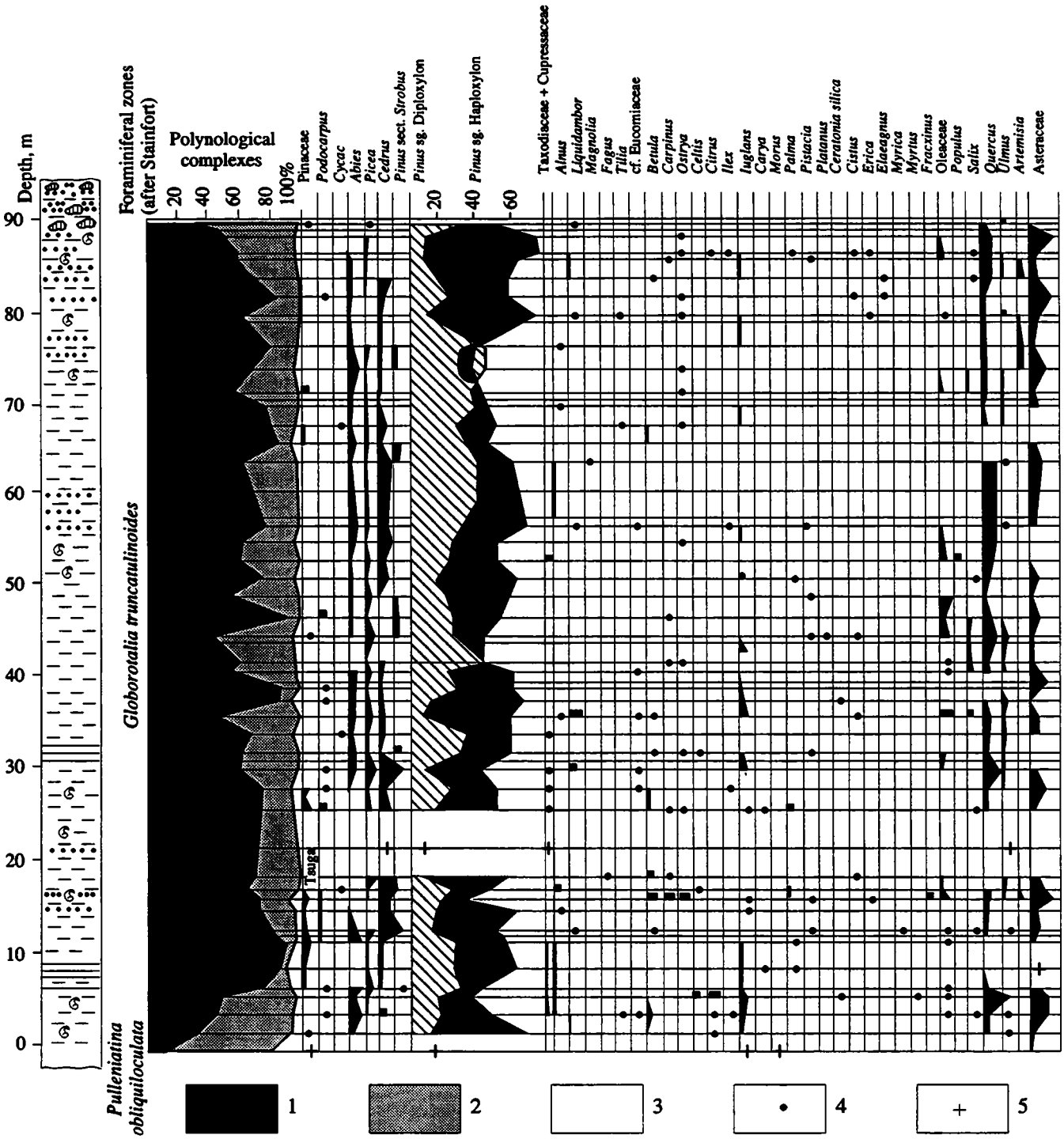
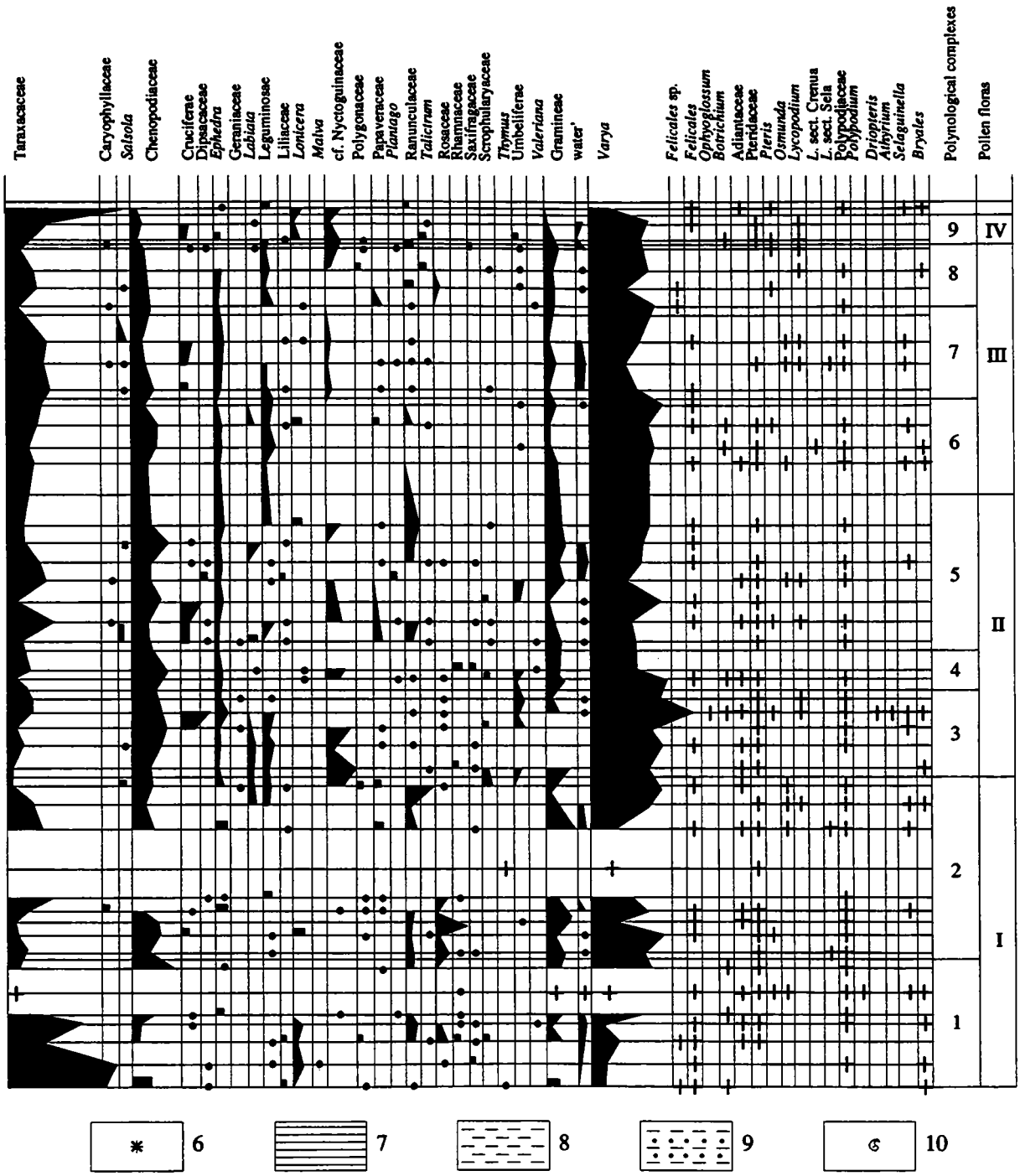


Fig. 1. Spore and pollen spectrum of the Mardido sequence.

1 – Arboreal and bush pollen; 2 – pollen of herbs and dwarf shrubs; 3 – spores; 4 – pollen grains of single occurrence; 5 – pollen and spores grouped by low pollen content (without counting percentage); 6 – appearance of species. Lithology: 7 – clays; 8 – silts; 9 – sandy silts; 10 – shells of mollusks.


Taraxacaceae
Caryophyllaceae
Salsola
Chenopodiaceae
Cruciferae
Dipsacaceae
Ephedra
Geraniaceae
Labiata
Leguminosae
Liliaceae
Lonicera
Malva
cf. Nyctoguinaceae
Polygonaceae
Papaveraceae
Plantago
Ranunculaceae
Talictrum
Rosaceae
Rhamnaceae
Saxifragaceae
Scrophulariaceae
Thymus
Umbelliferae
Valeriana
Gramineae
water'
Varya
Felicales sp.
Felicales
Ophyoglossum
Botrichium
Adiantaceae
Pteridaceae
Pteris
Osmunda
Lycopodium
L. sect. Cernua
L. sect. Selaginella
Polypodiaceae
Polypodium
Driopteris
Athyrium
Selaginella
Bryales
Polynological complexes
Pollen floras
9
8
7
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10

Fig. 1. (Contd.).

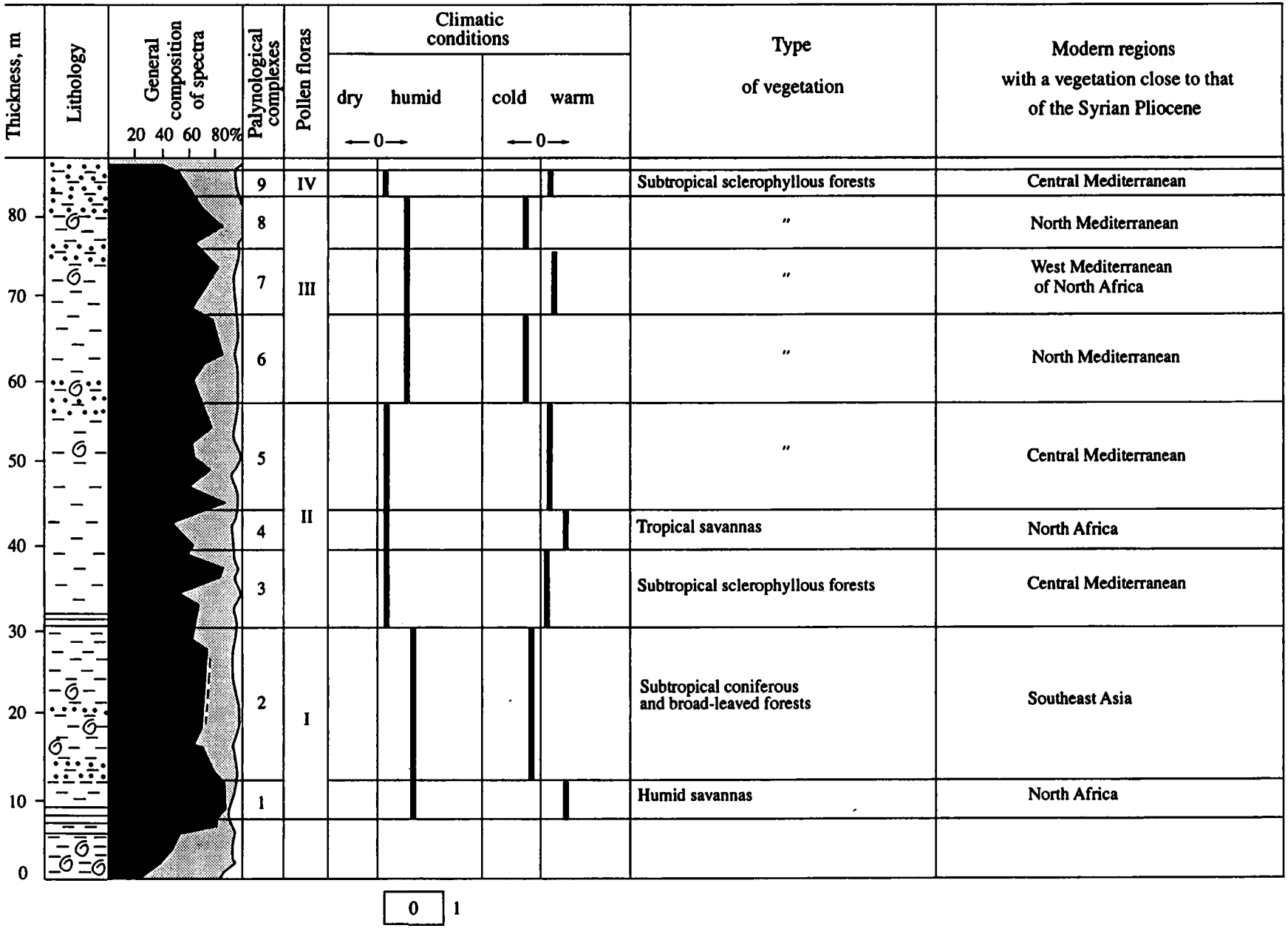

Fig. 2. Diagram of vegetational and climatic changes in the Late Pliocene of northwestern Syria.
1 – Modern climate; for symbols see Fig. 1.

The ninth palynological complex (9), recorded at a depth of 86 - 89 m, of the sequence constitutes pollen flora IV. In pollen spectra of the complex the content of arboreal pollen decreases whereas pollen of *Abies* and *Cedrus* disappear entirely. The quantity of *Pinus* sg. *Haploxylon*, Oleacea, and *Quercus* increases within the arboreal group, and Compositae, *Crucifera* and Nyctoquinaceae increase among herbs whereas the share of pollen of Chenopodiaceae and Graminae diminishes. Single occurrences of *Juglans*, *Erica*, *Ostrya*, and *Ilex* are recorded. A typical Mediterranean xerophytic vegetation, similar to the modern one, existed at that time.

Figure 2 illustrates a diagram of vegetation and climatic changes in the Late Pliocene of northwestern Syria based on a spore and pollen analysis of the Upper Pliocene Mardido sequence.

Four pollen floras recognized in the Late Pliocene of northwestern Syria account for regular climatic variations against the background of higher humidity as compared with the present time. Mediterranean-type evergreen sclerophyllous forests were a dominant type of vegetation. Changes in humidity were the basic climatic factor influencing vegetation. It is also dependant on the specific season of maximum humidity (summer or winter). In the middle of the considered time interval a relatively dry and cool climatic period was recognized.

Horowitz (1990) also recognized a relatively cool and arid period in the Late Pliocene in the territory of Israel. According to Bertolani Marchetti (1975), three pollen zones corresponding to two humid periods and one intermediate arid period are also established in the northern Mediterranean.

Thus, the climatic characteristic of the Late Pliocene of northwestern Syria correlates well with climatic data obtained for territories situated farther both to the south and to the north. In general, the Pliocene history of Syria, like the subsequent Pleistocene one, is characterized by a progressive aridisation alternating with arid and pluvial periods. These periods are reflected in temperature variations as well as in the succession of paleolandscapes with various types of Mediterranean and north African vegetation.

ACKNOWLEDGEMENTS

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BRIEF

COMMUNICATIONS

Seismostratigraphic Aspects of the Stratigraphic Code

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During the last decade or two, the methodological principles of seismostratigraphy were actively used in the study of the sedimentary cover of the Earth and, we are gratified to note, were incorporated into the second edition of the Russian Stratigraphic Code[1]. However, L.Sh. Girshgorn, the author of Chapter X, "Seismostratigraphic Units," has overlooked, unfortunately, a number of grave errors. On February 3, 1993, at a special session of the Seismostratigraphic Seminar, the members of the MOIP Geophysical Subsection discussed in detail the seismostratigraphic part of the Code. As a result, many of the suggested determinations were considered incorrect, and we were delegated the responsibility to voice the opinion of the Seminar in print. We intend, therefore, to indicate the main errors in the Code and to formulate our suggestions as regards the definition of seismostratigraphic units within the framework of stratigraphy, which will be submitted to the Stratigraphic Committee in due time.

(1) Seismostratigraphic units and their isochronous character.

According to the Code, the seismostratigraphic units; i.e., the geologic bodies, are confined by seismic horizons and substance boundaries[2] (clause X.1). The seismic horizons are characterized by the seismic signals corresponding to waves of a particular type (reflected, refracted, and converted) (clause X.2). This definition, however, distorts the notion of seismostratigraphy, because it is based on the analysis of reflections only, whereas the rest of geophysical information, including refracted and converted wave signals, is used as part of the integrated analysis to solve concrete problems. Consequently, the definition of seismostratigraphic units as layers with a reflected wave boundary at the top and a refracted wave boundary at the base (clause X.4) is a serious error. The seismostratigraphic units are detectable only on the reflected wave seismograms, because these waves alone detect isochronous horizons and synphase axes. This point is the basic principle of seismostratigraphy, without which it loses its meaning. The boundaries detected by refracted and converted waves are not isochronous and often migrate from one age level to another.

(2) "Substance boundaries" and their diachronous character.

The substance boundaries identify changes in substance-structural features (clause X.3). These features do not distinguish the units by their age, but indicate the facies, structural, and postsedimentary transformations in the section of the sedimentary cover. This is why they are meaningless as the age markers of the seismostratigraphic units. After Girshgorn, the substance boundaries are determined by the pattern of seismic records that characterize the facies peculiarities of the section. The isochronous reflecting horizons and the synphase axes often cut across the boundaries of the seismic record patterns. The same misrepresentations are seen in the description of local seismostratigraphic units (clause X.10), as they are also suggested to be seismic boundaries of any type (reflecting surfaces, changes in the seismogram patterns, and others). The anomalies of seismic impulses ("bright spot," "dark spot," and others) are erroneously referred to the local seismostratigraphic units, whereas actually these anomalies indicate facial changes in the section and rock saturation with fluids that are often used in exploration works for hydrocarbons. Thus, the local seismostratigraphic subdivisions would be the age units of a section, its facies peculiarities, and zones of post-sedimentation transformations, or even saturation with fluids.

Therefore, Chapter X of the Stratigraphic Code should be cardinally revised with due consideration of the actual achievements in seismostratigraphy and its basic methods. We suggest the following text to define the Seismostratigraphic units in the Code.

(3) Definition of seismostratigraphy and its purposes.

(3.1) Seismostratigraphy is a branch of science, whose primary task is the study of subhorizontally deposited layered bodies (bed associations) of the sedimentary cover produced by the interaction of tectonic and sedimentary processes and by sea-level oscillations.

(3.2) In seismostratigraphy, the graphic representation of the observation data consists of the time-scale seismogram obtained by various reflection methods: the common depth point technique (CDP), continuous seismic profiling (CSP), and high-frequency acoustic profiling. These seismograms show the layered medium as two-dimensional bodies filling certain parts of geologic space. The boundaries of the bodies are detected by

[1] *Stratigraficheskii Kodeks (Izdanie Vtoroe, Dopolnennoe)* (The Stratigraphic Code, the Second Edition, Supplemented), St. Petersburg: Mezhv. Stratigr. Komitet, 1992.

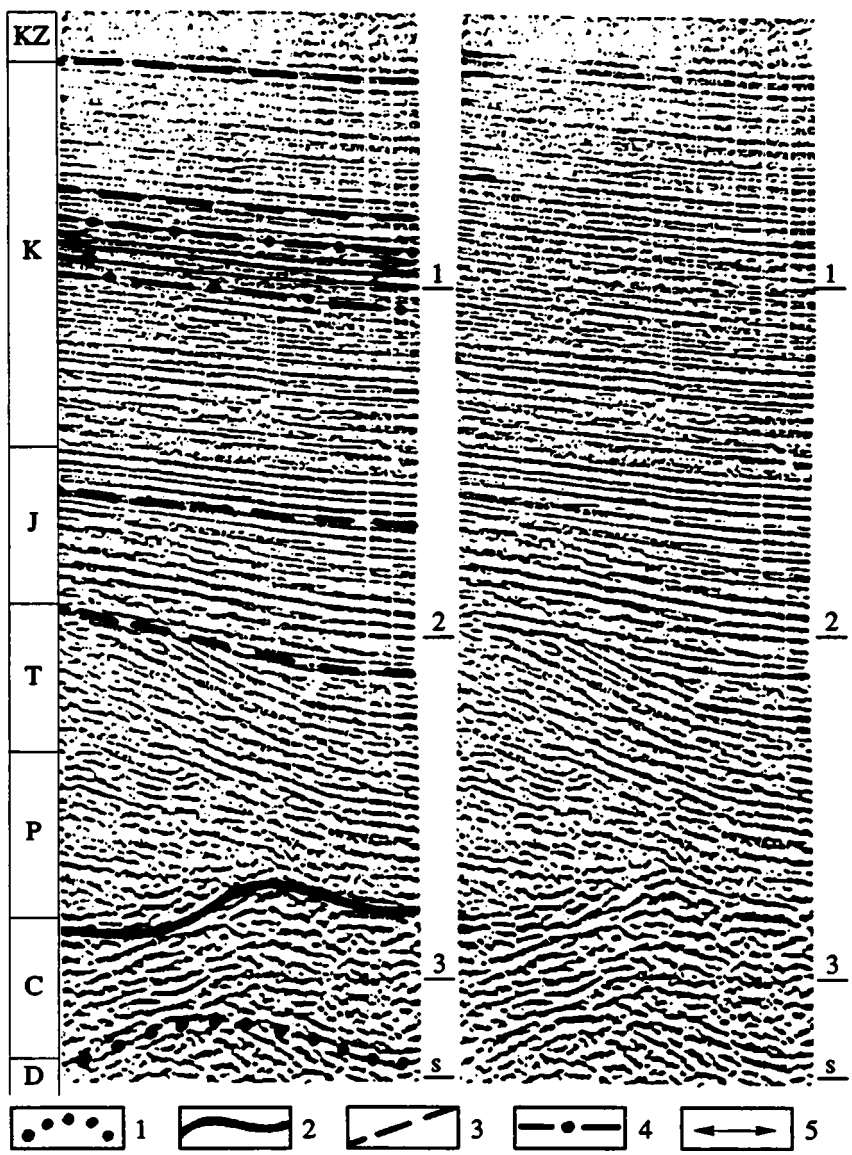
[2] This term is not used in seismostratigraphy and seismometry.

a system of reflecting horizons, smooth (when related to the rock layering) or rough (when confined to surfaces of erosional unconformity).

(3.3) The basic principle of seismostratigraphy is the isochronous character of seismic reflections related to the rock layering. The seismic reflections and seismic boundaries, originated as result of post-sedimentary processes, are rare and, as a rule, can be recognized on the basis of objective evidence.

(4) The application of seismostratigraphy in stratigraphic research.

(4.1) Under seismostratigraphic analysis, the seismic section is divided into three-dimensional (volumetric) geologic bodies according to their age. These bodies correspond to seismostratigraphic units of different rank, bounded by discordant or conformable surfaces. The seismostratigraphic unit of lowermost stratigraphic rank is dependent on the resolution ability of seismometry, and can not be less thick than 0.35 of the wave length. For most of the CDP seismic sections, the wave length varies from 30 to 15 m. If the high-resolution seismometry is used, then the value can be reduced up to 5 - 10 times and more, and seismostratigraphic units as thick as several dozens of centimeters can be detected. The minimal lateral dimension of the CDP seismostratigraphic units is several hundreds of meters, and increases with depth in proportion to the square root of the depth value. In high-frequency seismometry, their size is reduced to a few meters.



A fragment of a seismogram illustrating seismostratigraphic units of different stratigraphic rank.

1 – Base of sedimentary cover; 2 - 5 – boundaries of seismostratigraphic units: 2 – seismo stages, 3 – seismocomplexes, 4 – seismoassemblages, and 5 – seismoquanta.

(4.2) The stratigraphic rank of seismostratigraphic units can be determined from the vertical and lateral interrelations of the bounding surfaces. The stratigraphic distribution of seismostratigraphic units is delineated by the converging contours of their bounding surfaces, or by the disappearance of correlative reflecting horizons. In the latter case, a new seismostratigraphic unit is observed as a part of the vertical sequence with boundaries of different age levels.

(4.3) The successive series of seismostratigraphic units different in age forms the natural scale of event stratigraphy, which reflects the evolutionary stages of a sedimentary basin, or any part of it.

(4.4) The age of seismostratigraphic units can be determined by their correlation with the bore-hole sections or natural outcrops, characterized by paleontological and paleomagnetic data.

(4.5) The seismostratigraphic scales of separated sedimentary basins can be correlated only by means of comparative study on reference stratigraphic sections revealed by bore-holes or exposed in natural outcrops. The basal (coastal) on lapping patterns are still not used in plotting curves of sea level fluctuations and for the age determination.

(5) Seismostratigraphic units.

(5.1) The sedimentary cover is the largest unit representing the upper part of the crust and having a regular field of reflected seismic signals (see figure). The unit does not include sedimentary rocks of Phanerozoic folded structures with Apline-type deformations and crystalline rocks of the platforms basement. Its seismogram is stratified into layers by subhorizontal seismic boundaries. The base of the sedimentary cover overlies the top of the crystalline basement, or deformed sedimentary complexes of buried folded structures. In continental settings, these folded structures are screened, as a rule, by the basal layers of the sedimentary cover, and thus can notbe undetected by reflected seismic waves. In this case, the reference boundary at the base of the sedimentary cover can be recognized by refraction methods (DSS and RWM). On the other hand, the top of the oceanic basement is universally distinguished as the reference reflection boundary. In a lateral direction, the stratigraphic volume of the sedimentary cover changes because of rock transformations into folded or crystalline basement complexes.

(5.2) The seismostratigraphic stage corresponds to a large part of the sedimentary cover with an age interval of hundreds Ma, and a thickness up to several kilometers. This unit is uniform in structural style, being bounded at the top and base by angular unconformities.

(5.3) The seismostratigraphic complex is the principal unit of stratigraphic significance. The complex corresponds to a sedimentary member as thick as many hundreds of meters with an age interval of dozens of Ma. Rocks of a definite lithological composition prevail in every seismocomplex. Its top and base boundaries are usually confined to unconformity surfaces manifested as correlative reflecting horizons. Ideally, the seismic and sedimentary complexes should be equivalents. The latter correspond to eustatic cycles of sea-level oscillations of the third order (1 - 10 Ma) and contain layers deposited at low sea-level, transgression, and high sea-level phases. In the practice of seismostratigraphic research, however, it is often difficult to distinguish the eustatic sea-level variations in the sedimentary bedding.

(5.4) The seismostratigraphic assemblage (packet) is a part of the seismic complex. It is bounded by distinct reflecting horizons and has a regular internal structure. The seismoassemblage is less than 200 - 300 m thick, and has an age of a few Ma.

(5.5) The seismoquantum is the seismostratigraphic units of the lowermost stratigraphic rank. On a time-scale seismogram, it corresponds to a single total reflection. The seismoquantum can be described as a geologic body of a few meters thick deposited over a period of 1.5 Ma or a little longer. On the other hand, it can mark the bedding boundary.

(5.6) The seismocomplex is the seismostratigraphic unit of regional rank. It can be distinguished within the entire sedimentary basin or even in several conjugate basins. The seismoquantum and seismoassemblage are local seismostratigraphic units detectable in isolated areas. A seismoassemblage may include from 2 - 3 to 12 - 15 seismoquanta.

(5.7) The seismostratigraphic units represent the stratigraphic units of variable value and are dependent on the frequency spectrum of seismic waves and the sedimentation rate. In a lateral direction, the seismoquanta of the low-energy layers in sedimentary cover may grade into the seismoassemblages and the seismocomplexes of the high-energy layers.

(5.8) The appearance and disappearance of seismic reflections do not always have significance with regard to age. The seismic reflections of the detailed stratigraphic rank, i.e., the seismoquanta, show a tendency to converge and diverge, thus delineating the geologic bodies of various ages. If the seismic reflections are parallel, then quite often the age difference is not responsible for fluctuations in the synphase axes registration.

ACKNOWLEDGEMENTS

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Boris Sergeevich Sokolov is Eighty

Boris Sergeevich Sokolov, an outstanding geologist, stratigrapher, and paleontologist, Chief Editor of Stratigraphy and Geological Correlation turns eighty on April 9, 1994.

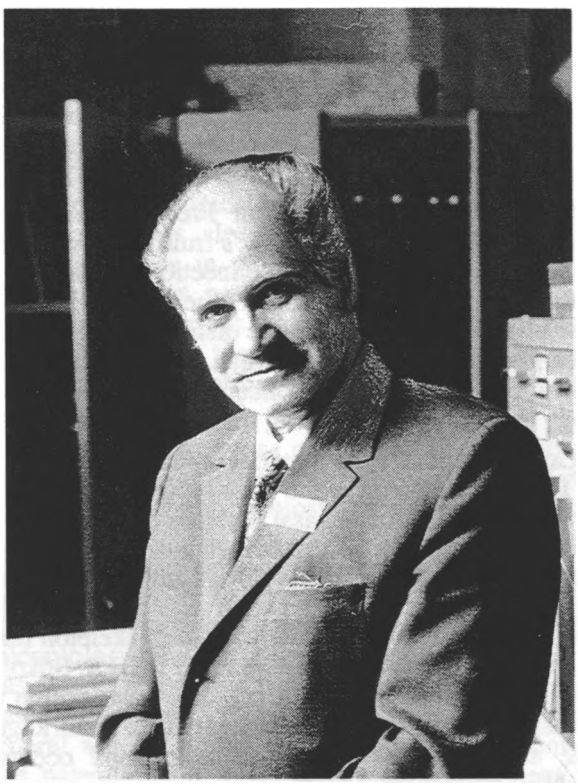

Photo made by P.N. Semenov-Tyan'shan'skii.

Academician Sokolov belongs to the world of prominent representatives of geologic science. He contributed much to stratigraphy, regional geology, paleogeography and facies analysis, and biosphere doctrine. His principal achievements are related to paleontology of corals and Late Precambrian stratigraphy, with distinction and substantiation of the Vendian system.

Boris Sergeevich was born on April 9, 1914 (March 28, according to the old style) in the City of Vyshnii Volochok into the large and friendly family of Sergei Borisovich (a doctor's assistant) and Dar'ya Andreevna, who had six children. He finished high school in his native town in 1931, and was going to enter the Leningrad University, but at that time entrance to higher education required labour experience. To obtain it Boris Sergeevich worked for a year as a repairman and was able to begin his studies at the Geologic-Soil Faculty of the University in the Autumn of 1932. In 1937, he graduated with honors from the University and was taken into the Department of Paleontology as an assistant. In those years, M.E. Yanishevskii was the head of the Department, whom Boris Sergeevich Sokolov recalls with affection as his first teacher in paleontology.

While at the University as a student Boris Sergeevich met Elena Nikolaevna Polenova, who soon became his wife. Later a well-known specialist in ostracodes and Devonian biostratigraphy of Russia, Elena Nikolaevna was for years Boris Sergeevich's closest relation until her death in 1987. She created a unique atmosphere of warmth within the family, protecting him from the troubles and difficulties of everyday life.

In the University and after graduation, the Carboniferous deposits and corals of the Moscow region were his principal objects of research, though his first publication was a work on Quaternary geology (1939). Studying Lower Cretaceous deposits in the Moscow region, Boris Sergeevich paid special attention to detailed investigations of corals (first of all to tabulate corals) and chaetetids, and in 1936 he also participated in geological expeditions in Central Asia, which were conducted by Leningrad geological institutions. While working there, he displayed his keen and extensive knowledge of geology and a talent for expedition organization as well. Thus, in the spring of 1941, it was B.S. Sokolov who was appointed to be one of the leaders of the Complex Expedition to western China, into Sinkiang, the purpose of which was to clarify geological structures and prospects for ores and oil. In 1941 - 1943, Boris Sergeevich investigated the Chinese part of Tien-Shan and the adjoining Tarim, Turfan, and Dzungar depressions, and in 1943 he was appointed as one of the chiefs of the Central Asia Expedition of the All-Union Oil Research Institute (VNIGRI). Until 1946, geological prospecting for oil and gas was conducted under his leadership. In the course of these investigations, significant scientific and practical results were obtained that were widely used by geologists of the former USSR and China, but remained unpublished. Until his move to Novosibirsk in 1960, Boris Sergeevich was engaged in researches in the field of petroleum geology. Investigations conducted during his second visit to China (1953 - 1954) with a group of experts to assess the region's oil and gas prospects are of special importance. For years, Boris Sergeevich maintained a special attitude towards China and visited it again in 1959, 1983, and 1987.

In 1945, B.S. Sokolov returned to Leningrad after completing investigations in Central Asia. While working in VNIGRI he renewed his teaching activity in the University. It was at that time that the sphere of Boris Sergeevich's scientific interests expanded. He started to work with material from reference drilling on the Russian platform and conducted wide lithologic-paleogeographic correlations, which were used in the atlas of lithologic-paleogeographic maps of the Paleozoic for the Russian platform and its folded framing.

Nevertheless, fossil corals that he had encountered during his school years were of primary importance in his work at that time. No comprehensive system for corals existed prior to the investigations conducted by Boris Sergeevich (primarily concerning tabulates), and the stratigraphic potential of the group was rated as very low. In his first work dedicated to fossil corals (1939), B.S. Sokolov determined the stratigraphic assemblages of chaetetids, marked their biogeographic peculiarities and, thus, for the first time presented this fossil group as a stratigraphic tool. His candidate thesis, defended successively in 1947, was also dedicated to chaetetids. The monograph, which represented this dissertation, was written in 1941 and published in 1950.

His personal participation in numerous regional investigations and growing scientific reputation signified that by 1950 B.S. Sokolov had gathered a bulk of material on tabulates from almost all the regions of the former USSR where they were recorded – the Russian platform, Urals, Siberia, Central Asia, the Baltics, and Podolia. Detailed study of this material resulted in the fundamental monograph "Paleozoic Tabulates of the European Part of the USSR," consisting of five volumes and later becoming a classic. These volumes, published in 1951 - 1955, comprise a monographic description of tabulates from different regions, the analysis of their stratigraphic significance, and a consideration of general aspects of classification and evolution of Tabulate corals as well as Heliolitids and Chaetetids. For each of these groups, skeleton morphology was considered, a taxonomic assessment of various features of their structure was given, microstructures and morphogenesis were described, and principal features of evolution were discussed. As a result, B.S. Sokolov suggested for the first time a unified taxonomic system of tabulatomorph corals (including Chaetetids, which at that time he considered as representatives of hydroids). One can hardly overestimate the importance of this work. To this day, it is used as a reference book for paleontologists-corallists around the world. In 1955, it was presented and successfully defended as a Doctoral thesis. Since 1958, Boris Sergeevich has held a professorship.

Seeking to understand the peculiar role of paleontology in the earth sciences, in the late 1950s Boris Sergeevich was among the organizers of a 15-volume series of summaries combined under the common name "Treatise on Paleontology." Boris Sergeevich was appointed Deputy Chief Editor of the Series (Chief Editor academician Yu.A. Orlov) and compiled chapters dedicated to Tabulate corals, Heliolitids, and Chaetetids. Principal leaders of this summary, including B.S. Sokolov, were awarded the Lenin Prize in 1967.

In 1958, B.S. Sokolov was elected corresponding member of the USSR Academy of Sciences and soon moved to Novosibirsk where the Siberian Branch of the Academy was organized at that time. In Novosibirsk, he was the head of the department of paleontology and stratigraphy at the Institute of Geology and Geophysics, which became a center for investigations of corals in Russia. Boris Sergeevich was an organizer of the First All-Union Symposium on Fossil Corals (Novosibirsk, 1963), and later of the First International Symposium dedicated to the same theme (Novosibirsk, 1971). Boris Sergeevich's initiative was supported by corallists around the world, and to this time six symposia have been successfully held. Recognizing his role in this initiative, Boris Sergeevich was unanimously elected Honorable President of the Washington Symposium (1983).

Investigations on the Upper Precambrian occupy a peculiar place in B.S. Sokolov's fruitful activity. Having began in the late 1940s in connection with investigations of pre-Devonian deposits of the Russian platform, these investigations resulted the distinguishing of a new Precambrian system, the Vendian, and stimulated the general development of a conceptual basis for paleontology and stratigraphy during the Precambrian as well.

Generalization of the material on the deep drilling at the Russian platform in the mid-1950s led Boris Sergeevich to conclude that basal horizons of the platform's sedimentary cover, which were then unanimously attributed to the Cambrian, made up an independent stratigraphic complex of Precambrian age. This complex, which preceded in appearance the oldest skeleton fauna of the Cambrian, was named Vendian by B.S. Sokolov. First distinguished only on a geologic basis within the Russian platform, the Vendian later gained historic-geologic and paleontologic substantiation and occupied a rightful place as the terminal system of the Precambrian. The Vendian gained wide recognition in Russia and abroad in this position. This is indicated by the wide usage of the term "Vendian System" in literature around the world and by the incorporation of the Vendian into the official stratigraphic scales of Russia in 1979 and 1990, as well as into some stratigraphic scales suggested abroad.

The extensive findings of Russian specialists obtained in paleontology, stratigraphy, and geologic history of the Vendian over the course of 30 years was generalized in the fundamental work "The Vendian System. Historical-Geological and Paleontological Substantiation." This bi-volume summary, planned by B.S. Sokolov as a wide synthesis of all available data, was issued under his editorship in 1985 in Russian, and in 1991 in a modified English edition.

The whole cycle of works by B.S. Sokolov on the Vendian system clearly demonstrates the attention that he paid to the paleontology of the Precambrian. Thus, in the late 1940s in VNIGRI, B.S. Sokolov organized micropaleontological investigations of Vendian

sequences. Application of paleontologic methods was not an instant success in the study of Precambrian fossils, the nature of which remained obscure. However intensive investigations conducted in VNIGRI, GIN, VNIGNI, and other leading geological institutes of Russia yielded significant results. In the 1960s, Russian scientists became leaders in a new "biostratigraphic" trend in Precambrian micropaleontology (within the Riphean and Vendian). The biostratigraphic scales of the Late Precambrian based on acritarch distribution throughout the Russian and Siberian platforms became the standard for all micropaleontologists dealing with the Precambrian. In his works, B.S. Sokolov constantly stressed the general methodological and practical significance of Precambrian micropaleontology.

Boris Sergeevich is credited with organizing and defining the principal trend in paleontologic investigations of the Precambrian. In the 1960s and 1970s, the lack of paleobiological interpretations concerning fossil material was clearly evident in contrast to the intense progress in paleontology in Russia. At that time, researchers paid attention to the stratigraphic application of various groups of Precambrian fossils, without analyzing their paleobiologic and paleoecologic aspects, preventing improvements in the biostratigraphic method.

Boris Sergeevich was one of the first scientists to grasp the significance of paleontologic studies of the Precambrian not only in biostratigraphy but also as tool in understanding the early stages of life evolution, as well as for enriching our understanding of the biosphere as a whole. He tirelessly popularized the "biologization" of paleontology in general and Precambrian paleontology in particular. An element of biology was always featured in the works of B.S. Sokolov dedicated to separate groups of Proterozoic fossils or to general aspects of life evolution in the Precambrian. The paleobiologic trend in investigations went well with the biostratigraphic trend in the Laboratory of Precambrian Paleontology, which was organized by B.S. Sokolov in the Paleontological Institute of the Academy of Sciences in 1976 after he had moved from Novosibirsk to Moscow. This was well demonstrated in studies of the oldest multicellular fauna of the Vendian and the traces of their vital activity. The description of the first findings of Precambrian fauna and the traces from the Vendian of the USSR prompted the development of Precambrian paleozoology in Russia.

Realizing the significance of modern data on the Precambrian organic life, B.S. Sokolov organized the First All-Union Symposium on Precambrian and Early Cambrian Paleontology in Novosibirsk in 1965. The Symposium attracted many specialists from Russia and abroad, and was successful in instigating investigations of Precambrian biosphere. Two similar symposia, organized by B.S. Sokolov in Leningrad in 1976 and in Petrozavodsk in 1987, appeared to sum up the major stages in the development of this timely trend in modern paleontology. Many specialists who started their investigations in the 1960s together with B.S. Sokolov or under his leadership made presentations at those symposia as scientists of international repute, owing to their achievements in the study of the organic world and Precambrian biostratigraphy.

Theoretical generalizations in Precambrian paleontology implemented by B.S. Sokolov always attracted specialists. Undoubtedly, B.S. Sokolov is considered a prominent theorist in this trend of science, which is briskly developing in countries around the world.

Defining the Vendian as an independent system seems to be the most outstanding achievement in stratigraphy to occur in the past decades. According to B.S. Sokolov's descriptive term, the Vendian period, containing specific biota, is a window through which one can see life evolution. Therefore, it is not by chance that B.S. Sokolov has been particularly interested in general regularities in the evolution of the biosphere and stratosphere. In this past decade, a series of his well-known publications were dedicated to these problems.

Boris Sergeevich's investigations concerning the boundaries of stratigraphic units and the development of the ecostratigraphic method should be noted. These works of general methodological importance were started in connection with the activity of the International Working Group on the Silurian–Devonian boundary, and later developed into an independent trend of B.S. Sokolov's theoretical investigations. In fact, he was the first to support and develop the concept of a global stratotype section and the exact boundary of a stratigraphic unit in published form. Many times he emphasized the necessity to typify stratigraphic units in order to develop an exact substantiation of chronostratigraphic units. A series of his works on Precambrian–Cambrian boundary is a good example of this.

Moreover, B.S. Sokolov's publications clearly show the efficiency of a complex approach to the development of a general Proterozoic stratigraphic scale. This conclusion, widely adopted in the Russian geological literature, is of special importance presently, in a time when the chronometric conception of general subdivision of the Precambrian seems most popular in English written literature.

In discussing the general methodological works of B.S. Sokolov we should point out that the notion of the special role of stratigraphy in the broad scope of Earth sciences runs through the majority of his books. This role, as Boris Sergeevich stressed in one of his publications, is indicated by the fact that only stratigraphy gives the time scale to transform geology into a historical science, i.e., into real science in the strict sense of the word.

The scientific-organizational activity of Boris Sergeevich should be given special mention. Since the foundation of the Interdepartmental Stratigraphic Committee (ISC) in 1955, B.S. Sokolov has been elected a member of its Bureau, the chairman of the ISC Commission on the Ordovician and Silurian, and a member of some other commissions. In 1971, he was elected

vice-chairman of the ISC, in 1976 its chairman, and in 1991 its honorable chairman. In 1962, Boris Sergeevich was elected vice-president, and in 1974 president of the All-Union (now Russian) Paleontological Society; in 1964 he was elected a member of the International Paleontological Union, in 1964 - 1966 he was the vice-president of the Asian Branch of this Union, in 1972 - 1980 the vice-president, and in 1980 - 1984 the president of the International Paleontological Association. B.S. Sokolov was one of the organizers of the International Geological Correlation Program. In 1975 - 1990, he held the post of Secretary-Academician of the Division of Geology, Geophysics, Geochemistry and Mining of the Academy of Sciences. His annual talks at the Division assemblies always exceeded the limits of formal reports about the activities of the Secretary-Academician and institutes of the Division, becoming an analysis of present-day problems of the Earth's sciences, considerations of their evolution trends, prospects, and challenges. His presentations, published annually in *Izv. Akad. Nauk SSSR, Ser. Geol.*, shows the progress of the Earth's sciences in the Academy.

As regards the programming introductory speeches of B.S. Sokolov at the annual sessions of the Paleontological Society, these were always noted for their deep analysis and innovate approaches to the problems posed; those speeches outlined the progress of Russian paleontology for the past decades, and deserved separate publication.

The creation of paleontological and stratigraphic division in the Institute of Geology and Geophysics, Siberian Branch of the Academy of Sciences, occupies a special place in the organizational activities of B.S. Sokolov. During a short period of time, B.S. Sokolov united a large group of paleontologists, biostratigraphers, and geologists in which over a hundred specialists worked in the 1970s. Boris Sergeevich elaborated a unique conception of investigations, and always kindly but strictly kept an eye on their development. As a result, Novosibirsk became one of the centers of paleontological and stratigraphic investigations ranging in the stratigraphic scale from the Riphean to Quaternary in the world. Since 1968, B.S. Sokolov has held full membership in the Academy of Sciences, a natural recognition of his scientific and organizational merits.

As a science organizer, B.S. Sokolov is characterized by purposefulness, exaction, a sense of perspective, an ability to define and formulate exactly the most urgent trends of investigations, a willingness to support young scientists, and a talent for locating and inspiring the specialist of different profiles to solve the problems that indicate the main line of science at present.

Boris Sergeevich was decorated with three Orders of Lenin, Order of the Red Banner of Labour, the Badge of Honour, and many medals. In 1984, he was awarded to the title of Hero of Socialist Labour, in 1967 – Lenin Prize, in 1979 – A.P. Karpinskii Gold Medal, the highest academic award in earth sciences, and in 1992 he was rewarded Karpinskii–Schweitzer Prize of the Hamburg Foundation and Carl von Baer Medal for geological investigations in Estonia. Boris Sergeevich is the author of more than 350 publications (including 9 books) dedicated to different aspects of geology, paleontology, stratigraphy, and the general evolution of the biosphere.

Brilliant scientific achievements won him immense prestige throughout the world. He was elected among the leaders of several international geologic organizations mentioned earlier, a member or honorary member of the geological societies of France (1963), Sweden (1968), Bulgaria (1977), U.S.A. (1983), Great Britain (1985), Canada (1987), a member of Czechoslovak Academy of Sciences (1982), and Academy of Sciences of the former GDR (1986). He is an active member of commissions on the legacies of I.A. Efremov, V.I. Vernadsky, A.P. Karpinskii, D.V. Nalivkin, and the Rerichs.

Boris Sergeevich made valuable contributions training specialists. For a long period, he was closely connected with the chair of paleontology in Leningrad University until his move to Novosibirsk, where he continued teaching, serving as an organizer, and the head of the Chair of paleontology and historical geology in Novosibirsk University. Under the supervision of Boris Sergeevich, many of scientists became well-known in Russia and abroad, in Vietnam, Bulgaria, Poland, and China.

The general education activities of B.S. Sokolov are immense. They continued for many years through contacts with colleagues, students, in numerous speeches before scientific and amateur audiences, in dozens of publications in newspapers and journals, and in radio and TV interviews. The rate of scientific achievements, gift of eloquence, style of investigations, and comprehensive school of followers puts Boris Sergeevich among the most brilliant representatives of the Russian Academy of Sciences.

The division of Geology, Geophysics, Geochemistry and Mining.
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The Russian Paleontological Society. United Institute of Geology, Geophysics, and Mineralogy, Siberian Division of Russian Academy of Sciences.
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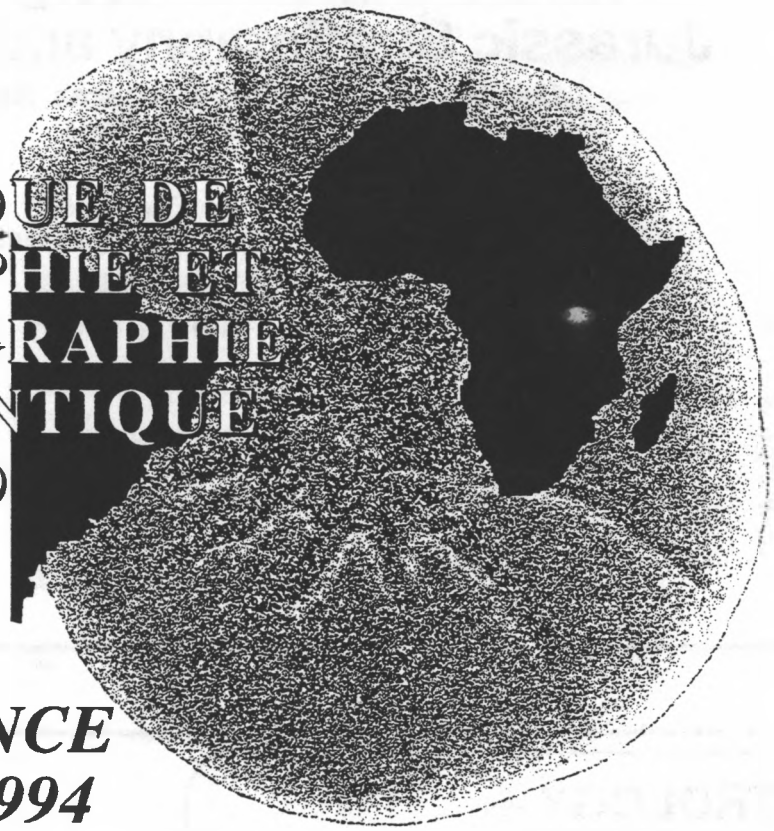

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Ten Colloquia of African Micropaleontology have been organized in African countries or in France since the first one took place in Dakar in 1963. The proceedings of these colloquia lead to about 5500 pages that provided essential data concerning West African and South American basins.
In 1991, in Libreville (Gabon), the 11th Colloquium of African Micropaleontology was grouped with the first Colloquium of Stratigraphy and Paleogeography of sedimentary basins of West-Africa. During this Colloquium several papers were presented concerning Brazil. Thus it seems judicious to extend the 1994 Colloquium to the whole basins surrounding South-Atlantic Ocean.

The 12 th African Micropaleontological Colloquium and the 2nd Colloquium on the Stratigraphy and Paleogeography of the South Atlantic will be organised in july 1994 at the Geological Institute of the University of Angers, France. The langages of the colloquia will be French and English.

The proceedings will be published in a special issue of the **"Bull. Centres Rech. Explor.-Prod. elf. aquitaine"**. Before acceptance, each paper will be submitted to two reviewers.

INFORMATION

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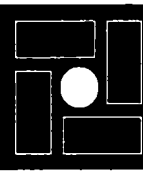

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